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THE T.E.S. "SAN SILVESTRE"

The turbo-electric ship "San Silvestre", of 15,900 tons deadweight, is the first of two tankers to be built by the Furness Shipbuilding and Engineering Co. Ltd. for the Eagle Oil and Shipping Co. Ltd. The electric drive, provided by the G.E.C., includes a 9,000 s.h.p. propulsion motor supplied from a 3·23 kV turbo-alternator.

# A 250 Kilovolt X-Ray Equipment for Deep Therapy

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*Apparatus for deep X-ray therapy has hitherto failed to combine adequate output with reasonable size or freedom from the disadvantages of unwieldy shockproof high tension cables. The design of Watson apparatus Type XT-1 is a new approach to the problem. It has a rating of 250 kVP., 18 mA. with a tube-head of relatively small proportions and cables which are required to withstand only approximately a quarter of the total tension.*

## INTRODUCTION.

THE requirements of an X-ray generator for the treatment of deep-seated tumours may be briefly summarised under the headings of output, positioning and safety. The radiation output must be sufficient both in intensity and in penetrating power to administer the required dose in a reasonably short time. It must be possible to adjust easily and quickly the positions of both the patient and the X-ray beam to the radiologist's requirements. The equipment must be protected against accidental damage to the patient, the operator, or the apparatus itself, so that the operator may concentrate as much as possible on the needs of the patient and the correct administering of the treatment. In addition, a high degree of reliability is required, and every reasonable precaution must be taken against alarming the patient, who may already be in a very nervous state, by either the appearance of the equipment, or any noise produced by it in operation.

In general, the first two requirements of adequate output and easy positioning are conflicting factors in the design, since an increase in output will usually mean an increase in size and weight and therefore some sacrifice in ease of manipulation. As a result, every design must be, to a considerable extent, a compromise between these two requirements.

There have in the past been two main methods of approach to this design problem. In the first, or shockproof tube type of equipment, only the X-ray tube itself in its shockproof housing is movably mounted for the adjustment of the beam position ; the associated high tension generating equipment is stationary, and must therefore be connected to the tube by flexible high tension cables. In the second, or " transformer type " head, the X-ray tube and high tension transformer are contained in one tank and are movable as a whole for positioning of the beam, with flexible low-voltage connections to the power supply.

Both these types of X-ray generator are familiar in the lower voltage, lower power range of diagnostic and superficial therapy equipment, in which the transformer-head is most frequently used for the smaller dental and mobile units, and the shockproof tube for the larger fixed diagnostic installations and for superficial therapy up to about 150 kilovolts peak. With the increase in kilovoltage to at least 200 kVP for deep therapy, the larger high tension cables required begin to impose considerable restraint on the easy movement of the tube head, with the result that the transformer-head again becomes a competitive design, but only just competitive, since the bulk and weight of the generator also impose their limitations on the ease of manipulation of the head.

In the equipment to be described, an attempt has been made to arrive at a better overall compromise than is achieved in either of these types by adopting what may be described as the middle course of a " divided-generator " design, in which part of the high tension generator is contained in the movable head with the X-ray tube, and the rest of the generator is stationary and is connected to the head by cables operating

at an intermediate voltage. The result is that the head is considerably smaller and lighter than the usual transformer-head and is substantially free from the restraint of the high tension cables of the shockproof tube.

In this equipment, as in the other two types, the high tension generator is arranged symmetrically in the circuit, on either side of the X-ray tube, that is between each of the tube

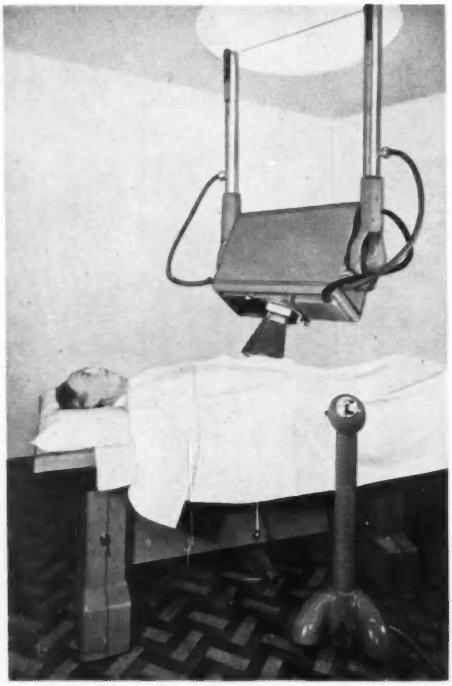

Fig. 1.—250 kilovolt X-ray head in a ceiling mounting, with treatment couch and pedestal control for the motor-driven vertical movement of the head.

electrodes and earth. For the total of 250 kVP, therefore, the anode is supplied with 125 kVP positive to earth, and the filament is supplied with 125 kVP negative to earth. Each half of the generator is again subdivided into two sections of approximately equal voltage, so that between each tube electrode and earth there is one section of the generator contained in the tube-head and supplying about 62·5 kVP and a stationary section which also supplies about 62·5 kVP. The cables connecting the stationary sections of the generator to the head therefore carry only a quarter of the total voltage, and can be of the type commonly used in radiographic equipment. At this voltage too it is possible to take the high tension connections into the head through sliprings so that rotation of the head about one axis is obtained without any movement of the cables.

In this way it has been possible to make a head measuring only 29 by 24 by 12 ins. in which the tube operates at 250 kVP, 18 mA, and in which no restraint is imposed by the high tension cables on the easy movement of the head for adjustment of the beam to the treatment position. Fig. 1 shows a view of the head in a ceiling suspension.

The radiation output from the head, measured free-in-air at 50 cms. from the target, is shown in fig. 2. The lower curve shows the output intensity, in roentgens per minute, plotted against the added filtration in millimetres of copper followed by 1 millimetre of aluminium. In the upper curve, the hardness or penetration of the radiation, measured by the half-value-layer in millimetres of copper, is plotted against its intensity.

## THE CIRCUIT OF THE DIVIDED GENERATOR.

The principle of the divided generator employed in this equipment may be used with any of a number of circuit arrangements, one of which is illustrated in fig. 3. In this the two sections contained in the head are shown simply as transformers, supplying an alternating high voltage. This is the simplest and most suitable form of generator for containing in the head as it is the most economical in weight and bulk.

Each stationary section of the generator supplies a rectified potential from a single-phase half-wave rectifier circuit. Two arrangements of these D.C. generators have been used. In the one illustrated, the output is smoothed by a condenser, so that the total voltage across the X-ray tube has a wave-form similar to that of the Villard circuit. This has the advantages that there is little or no inverse voltage on the tube and that the cables are operating under the extremely favourable condition of constant potential. In the second arrangement the rectifier output is left unsmoothed, with the advantages of easier operating conditions for the rectifier valves and a somewhat greater radiation output from the tube, as the useful voltage wave-form is a half-sine-wave, which has a greater effective value than the Villard-type wave-form. The cables operate under a pulsating rectified voltage which, though more severe than the constant potential, is still well within their capabilities. The tube operates with an inverse potential, but this is not an important factor in the tube life as its magnitude is only about half that of the operating peak kilovoltage.

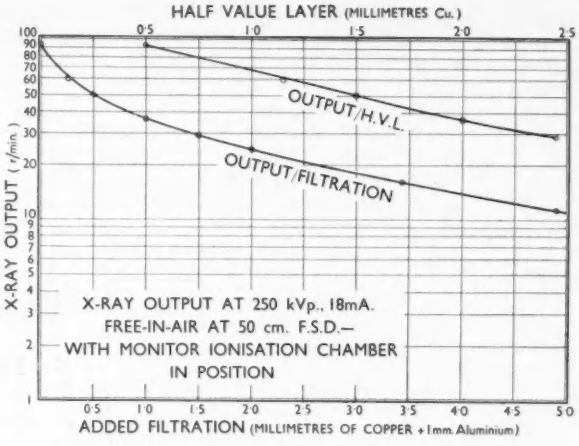


Fig. 2.—Radiation output characteristics at 250 kVP, 18 mA.

These stationary generators also contain isolating transformers which operate with their secondaries at the output D.C. potential, and supply, through two cores of the high tension cables, the primary voltage to the transformers in the head. On the cathode side a further isolating transformer supplies the primary voltage of the tube filament transformer in the head, through one of these cores and a third core in the cable at the cathode end.

### ARRANGEMENT OF THE TUBE HEAD.

The design of the tube head itself is illustrated diagrammatically in fig. 4.

The two high tension transformers and the tube filament transformer are mounted on one side of an insulating panel, with the X-ray tube mounted on the opposite side. The tube is enclosed by three shields in the form of lead alloy castings which serve the dual purpose of cutting off stray radiation and defining the electric field round the tube envelope.

The centre shield is at earth potential. The two shields which enclose the ends of the tube and the casings which similarly shroud the windings of the high tension transformers are each connected to the appropriate incoming high tension from the external generators. The additional high voltage supplied by the transformers is generated within the shrouds and is brought through the insulating panel to castings which support the tube ends within the lead end shields.

The whole assembly is oil-immersed in a welded steel tank which is at earth potential. Thus the oil insulation for 125 kVP between each end of the tube and earth is everywhere divided into two approximately equal parts. This not only results in some economy of space, but also makes the design no more difficult than that of radiographic or superficial therapy equipment of approximately half the total kilovoltage.

The steel containing tank is fitted at each end with a ballrace mounting and, concentric with it, a high tension bushing which carries the supplies from the external generators. In the lid of the tank, mounted in a lead alloy flange, is the hard glass window through which the X-ray beam is directed, and a second cover-plate over the lid carries the shutter, monitor ionisation chamber and fittings for the filters and applicators for control of the beam.

The X-ray tube can be replaced on site without removing the head from its suspension. The whole head is enclosed in a highly-finished sheet metal outer casing which is lead-lined to provide a final overall protection against the escape of leakage radiation from the tank walls.

### THE EXTERNAL GENERATORS.

The design of the external D.C. generators, one of which is shown in fig. 5, presents no special problems. Except for the difference in polarity and the extra isolating transformer in the negative generator, to supply the tube fila-

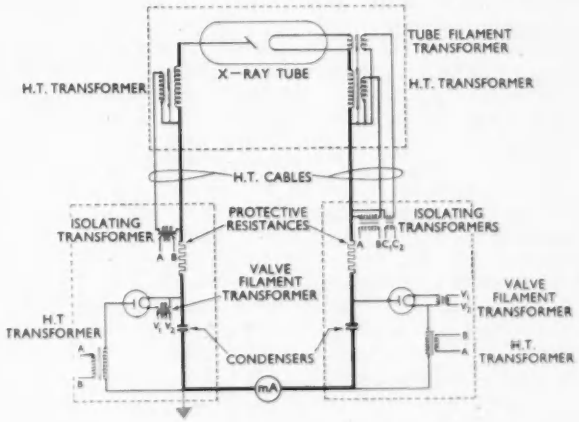


Fig. 3.—Basic circuit of the divided high-voltage generator.

ment transformer in the head, the two generators are identical. In each the circuit components are contained in a welded steel tank which is oil-filled for insulation and cooling. The rectifier valve is also immersed in the oil and is

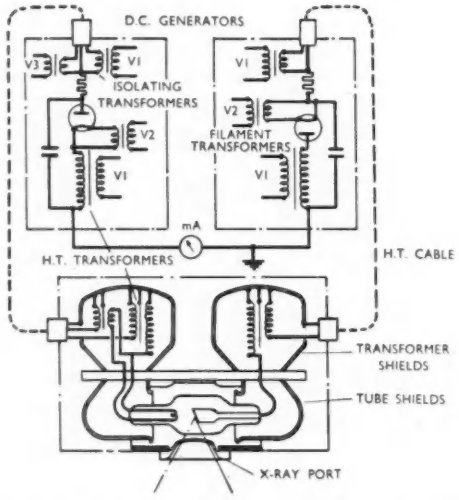


Fig. 4.—Schematic diagram showing the internal arrangement of the tube-head.

easily replaceable through a hand-hole in the lid of the tank. The tank top also carries the socket for the high tension cable which connects the generator to the tube head.

## THE CONTROL UNIT.

The desk-type control unit is of low height so that the operator can see over it through a lead-glass window into the treatment room. The lower part of the desk is an angle-iron framework on which all the main components are mounted as shown in fig. 6, while the top is built up of light alloy castings. All the instruments, controls, switches and pilot lights are mounted on the upper front panel which is hinged to open downwards for easy maintenance.

The three central instruments are a voltmeter showing the tube kilovolts and two milliammeters, one in series with each D.C. generator, to show the tube current. Above these is the scale of a mirror galvanometer which reads directly the current through the ionisation chamber mounted in the head. Its reading is a measure of the radiation output and therefore acts as an overall monitor on the tube voltage, tube current and beam filtration.

To the left of the instruments is a synchronous motor-driven timer to control the duration of the treatment. It has two dials, one scaled in seconds up to one minute, and the other in one-minute steps, giving together a total scale of fifty-five minutes in one-second steps.

To the right of the instruments is the kilovoltage control handle which operates a face-plate type switch with 81 studs connected to an auto-transformer giving a control range of 120 to 250 kVP. This regulator is variable on load, the connecting leads between transformer and switch forming the windings of an iron-cored reactor which limits the short-circuit current when the brush bridges two adjacent studs. The tube current control is mounted directly below the kilovoltage regulator, and provides coarse and fine adjustment on concentric knobs.

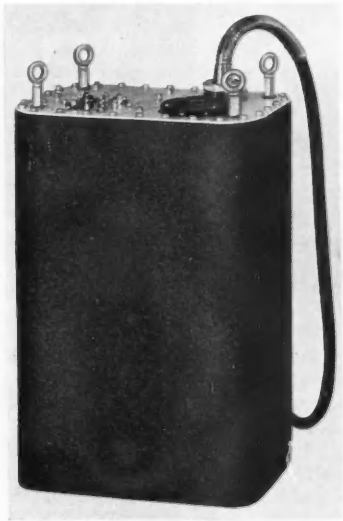

Fig. 5.—One of the rectifier sections of the high-voltage generator.

Two features of automatic compensation, which greatly simplify the adjustments of the set, are obtained by the arrangement shown in fig. 7 which shows the compensating circuits applied to a self-rectified tube circuit. The tube current is made substantially independent of the kilovoltage by a compensating transformer which decreases the voltage supplied to the tube filament as the kilovoltage is increased. The kilovoltmeter, which measures the input voltage to all sections of the H.T. generator, also has automatic compensation to correct its reading for the regulation of the generator as the tube current is varied. This is done by using a

rectifier-type voltmeter and feeding a fraction of the load current through the moving coil of the instrument in opposition to the rectified current supplied from the generator primary voltage. The tube and rectifier valve filaments are supplied from a voltage stabiliser, so that they are independent of supply voltage variations.

The control switches are arranged in correct sequence along the bottom of the panel and interlocks are provided to ensure that the sequence is followed. The cooling water must be flowing before the oil circulating pump can be started or the head energised. This interlock is so arranged, however, that should the water supply fail during a treatment the head will not be switched off immediately, but will continue to operate as long as the oil temperature does not exceed the limit permissible for safety of the X-ray tube.

Before the high tension can be applied to the tube several conditions must be met. The rectifier valve filaments must be alight, the oil flow must be adequate and oil temperature not excessive, the door of the treatment room must be closed, the kilovoltage must be at minimum, there must be a filter in place in the head, and finally the operator must have made a check that the filter is the correct one. This is done by means of the eight push button pilot lamps in the bottom centre of the panel corresponding to the eight different filters for which provision is made in the head. The push buttons are marked with the characteristics of the filters and the one corresponding to the filter in position must be operated before the tube can be energised. This check must be made when the set is switched on or if the door of the treatment room has been opened, and the appropriate pilot lamp remains alight during treatment as an indication of the filter being used.

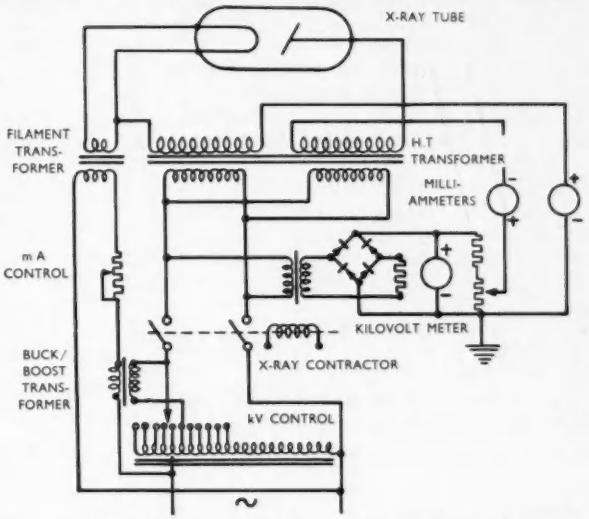


Fig. 7.—Tube-current and kV meter compensating circuits, in a self-rectified tube circuit.

Fig. 6.—Control with writing ledge and panels removed to show the simple and accessible layout.

With the tube energised, the current and voltage can be set to the required conditions and with the timer adjusted to the required treatment time the shutter can be opened by a final switching operation. At the same time, the timer starts to operate and the deflection of the galvanometer spot indicates that the shutter is, in fact, open and that the beam is of the required intensity. If the treatment is interrupted, the timer stops and is started again when treatment is resumed, so that the correct total time is given.

Shortly before the end of the preset time a warning buzzer is sounded, and

finally the timer automatically terminates the treatment by closing the shutter. If the door of the treatment room is opened the head is automatically de-energised, so that the operator is not exposed even to the low level of radiation present with the shutter closed.

A final precaution operates when the set is shut down, and ensures that the flow of cooling oil continues for at least one minute after the tube is de-energised to remove the heat energy stored in the tube anode.

Built into the control desk there is a two-way loud-speaking intercommunication system between the control and the treatment room, which can be switched over if required to the generator room above to enable a maintenance engineer servicing the equipment to communicate with the control room.

## MOUNTING OF THE HEAD.

In the type of mounting illustrated in fig 1 and shown diagrammatically in fig. 8 the tube head is suspended between two supporting tubes from the ceiling of the treatment room, so as to have the floor-space around it free of any encumbrance to the positioning of the treatment couch. The head hangs in ball-bearing trunnions lying on a horizontal axis through its centre of gravity so that it can be rotated freely through 280°. The supporting tubes are carried by a turntable mounted on a large ball-race on the floor of the generator room above, on which the whole assembly can be rotated through 180° about a vertical axis, so that the beam can be directed to any required angle in both vertical and horizontal planes. Both these movements are free enough to be hand-operated and are provided with angular scales and locks so that a treatment position can be accurately set and will not be disturbed accidentally by the patient.

The height of the head is adjusted by a motor-driven rack and pinion gear raising and lowering the supporting tubes through the turntable. The height of the focal spot above floor-level is adjustable from 18 ins., with the beam directed upwards, to 78 ins. with the beam directed downwards. The full range of movement can be covered in thirty seconds, but for accurate positioning a slow speed is also provided and electromagnetic brakes prevent overrun of the motors.

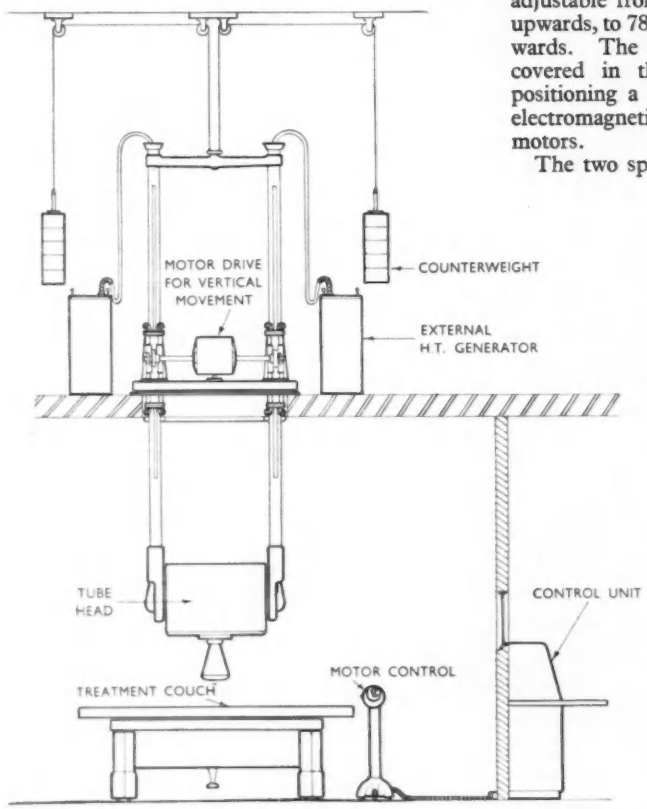


Fig. 8.—Schematic elevation showing the arrangement of the ceiling suspension.

The two speeds are obtained by two motors, one with a five to one reduction gear, operating through worm gears on to a differential, which enables either motor or both together to drive the cross-shaft and pinions engaging with the racks on the supporting tubes. Although the suspension is counterweighted, the gear train and brakes are made strong enough to support the whole suspended mass, so that double security is provided against accidental descent of the head on to the patient. The turntable mounting, with motor-drive and differential gear box are shown in fig. 9, in which the oil reservoir, mounted on the top cross-member of the supporting columns, can also be seen.

The vertical movement is controlled by a hand lever mounted on a control pedestal, shown in fig. 1, which can be moved to any convenient position in the treatment room. The control lever selects the speed and direc-

t on of movement through a system of relays, but t prevent accidents through failure of the relays t open, a foot-switch at the base of the column i connected directly in the supply leads to the driving motors and must be depressed to operate the drive.

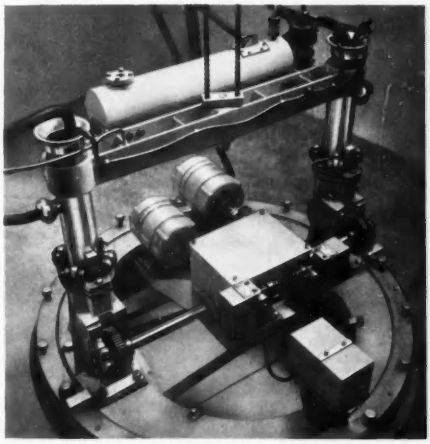

Fig. 9.—Turntable of the ceiling suspension showing the driving motor and gear box and the oil conservator.

The two stationary sections of the H.T. generator stand one on either side of the turntable and the H.T. cables feed through the supporting tubes to slipring connections concentric with the trunnion mounting of the head. The head can therefore turn about the horizontal axis without movement of the cables; in the rotation about the vertical axis the cables are flexed in the free-hanging loops between the two generator sections and the tops of the supporting tubes.

This type of mounting, with the generator room above and the treatment room free of unessentials, is ideal where it can be accommodated. In many existing hospitals, however, it cannot be used because of some limitation such as ceiling height or space on the floor above. An alternative floor-mounting has therefore been designed which gives almost as much freedom of movement around the head and provides a similar range of movement of the head itself.

In the floor-mounting, the auxiliary equipment from the generator-room is housed in a cabinet standing against one wall of the treatment room. A horizontal tube projecting from the cabinet carries the head in a gimbal mounting at its further end. This mounting provides the same range of motor-driven vertical movement by raising and lowering the supporting tube on two columns contained in the mounting cabinet, but instead of rotating about vertical and horizontal axes the head rotates 180° about the horizontal axis of the supporting tube and 250° about the gimbal axis which is at right angles to it and parallel to the tube axis.

The centre of the head stands 4 ft. 6 ins. from the front of the mounting cabinet so that there is no significant limitation on the positioning of the treatment couch. By keeping the weight of the D.C. generators, the counterweights for the vertical movement and the oil-pump and cooler as well back in the mounting cabinet as possible, the overhanging weight of the head is counterbalanced so that the whole structure is self-supporting on the floor and only needs a light fixing to the wall.

### INSULATING AND COOLING OIL SYSTEMS.

The H.T. transformers in the head are oil impregnated under vacuum after assembly in the tank, and the tube mounting is designed so that the transformers remain under oil while the tube is removed or replaced. An oil pipe running through one of the supporting columns connects the head to a conservator tank at the top of the columns to allow for oil expansion.

A separate oil system provides cooling for the tube anode. A pump in the cooling oil reservoir circulates the oil through tubes contained in the supporting columns to internal oil passages in

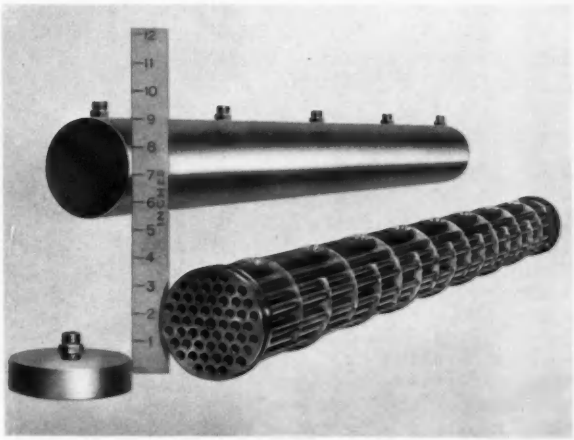

Fig. 10.—Oil-to-water heat exchanger ready for final assembly.

the anode and then to a heat-exchanger where it is water-cooled before returning to the reservoir. The oil pipes inside the head are partly of insulating material, and here again advantage is taken of the intermediate potential point to separate the insulation in both inlet and return pipes into two 62·5 kV sections.

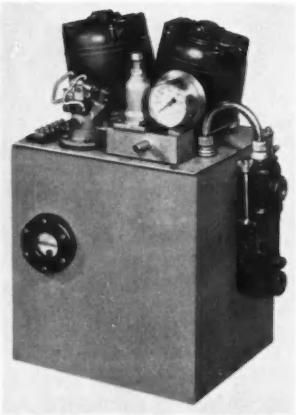

Fig. 11.—Oil reservoir and circulating pump unit.

In the oil-to-water heat exchanger, the oil flows through a tubular jacket in which it is constrained by baffles to take a zigzag course across the cooling tubes which run from end to end of the jacket and through which the cooling water flows in the contrary direction to the flow of oil. This system of cooling pipes and baffles can be seen in fig. 10 which shows a cooling unit before final assembly.

By passing the water-pipes right through the end plates of the oil jacket to separate inlet and outlet headers at the ends, the risk of leakage of water into the oil is reduced to a minimum.

The oil reservoir and pump unit is shown in fig. 11.

The oil pump is of a conventional helical gear type, but noise and wear have been reduced to a minimum by driving the gears independently from two similar motors, so that no appreciable power is transmitted from one gear to the other.

## CONTROL OF THE X-RAY OUTPUT.

The duration of the X-ray exposure is controlled by a shutter consisting of two balanced lead plates which are driven by an electric motor operated from the control desk.

The radiation quality is controlled by a system of interchangeable metal filters which slide into the tube head. Each filter completes a circuit through one of a series of contacts which connect with the push button checking system on the control desk.

After filtration, the beam passes through a monitoring ionisation chamber, and the ionisation current produced, which is a measure of the radiation intensity, is measured by the monitor galvanometer in the control. The chamber is hermetically sealed, so that the density of the contained air, and, therefore, the current produced in it, are independent of changes of temperature and barometric pressure.

The range of applicators which define the beam cross-section and treatment distance fit into a slide which is mounted on a large ballrace permitting 360° rotation about the beam axis. Each applicator has a cast aluminium body supporting two lead diaphragms, one at the tube end to confine the beam within the applicator walls and a second near the patient end to reduce the penumbra produced by finite focal spot size in the X-ray tube. The applicator end is made of "Perspex" for ease of positioning, and is easily removed for cleaning.

Surrounding the applicator base-plate is a firmly supported annular plate, also rotatable through 360° about the beam axis and carrying a fitting to which may be attached whatever type of device may be required for beam centring.

Fig. 12.—Beam control equipment on the tube-head.

The view of the tank top in fig. 12 shows how ıe beam control components are mounted on ıe head.

This whole assembly of beam controlling .evices is mounted on a base-plate which is djustable on the tank top, and a special fitting, nterchangeable with the applicators, is provided vhich enables it to be set up in accurate alignnent with the X-ray source.

### TREATMENT COUCH.

In most cases the setting-up of a treatment position cannot be accomplished entirely by adjustment of the tube-head. The treatment couch carrying the patient must also be easily moved around so that the X-ray beam and the part to be irradiated can be adjusted to their correct relative positions.

In some treatments it is an advantage to compress the patient slightly with the end of the applicator, so as to displace some of the superficial tissue and increase the dose to an underlying tumour. In this equipment the vertical movement of the head is controlled accurately enough for this compression to be effected by lowering the head slowly on to the patient. This may, however, be a rather alarming experience for a patient who may be very ill or very nervous of the experience of X-ray treatment. It is much less alarming if the head is stopped an inch or two above the patient's body and the compression obtained by raising the patient against the applicator by a movement directly operated by the radiographer.

The treatment couch is therefore an important item in the therapy equipment and the couch illustrated in fig. 13 is supplied as an integral part of the complete installation.

The couch can be moved freely about the floor on four double-wheel castors, and the base of the couch can be locked firmly in position by a floor-lock. The top is then movable on the base for final adjustment, with an 18 in. travel along, and a 6 in. travel across, its length. These two movements have locks which can be released either independently or simultaneously if a diagonal travel is needed.

The couch top can be raised through 6 ins. by a pedal operated hydraulic jack which drives four coupled gears engaging with racks, one at each corner, so that the top is raised uniformly as a whole and is rigidly supported at all heights. A release valve on the jack allows the top to fall again under its own weight.

All the controls for the floor-lock, for raising and lowering, and for the horizontal movements of the couch top are duplicated, one set at each side of the couch so as to be readily accessible to the operator from any position.

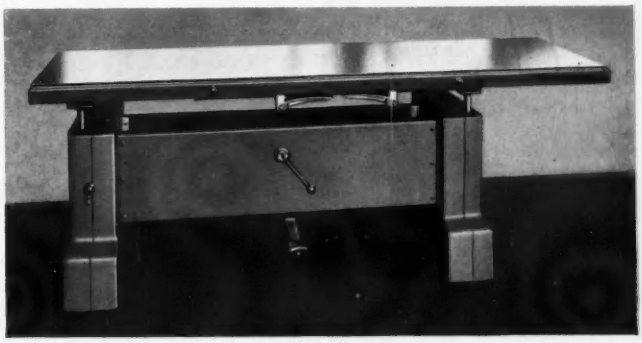

Fig. 13.—Treatment couch.

### FINISH.

Most X-ray therapy equipment is finished either in black or in a light cream shade. Neither seems ideal for the purpose ; the black because of its depressing effect and its tendency to enhance the apparent bulk of the apparatus suspended over the patient, the cream because it suggests the operating theatre and also because of the difficulty of reproducing the shade if auxiliary equipment should be required to match.

In this equipment the experiment has been tried of finishing in pale green enamel with chromium plating and polished aluminium on some of the working parts. The tube head, couch and control desk are all finished in this colour, and even the operator's chair is in a matching shade of green leather.

The whole effect is very pleasing and has received much favourable comment from radiologists who recognise that consideration for the mental state of the patient is a not unimportant factor.

### ACKNOWLEDGMENT.

The authors would like to make acknowledgment to their many colleagues at the Union Works, Wembley, for their work in connection with the design of the apparatus described.

# Review of the Applications of V.H.F. Radio Communications

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G.E.C. Radio Department.

## INTRODUCTION.

DURING the last decade considerable advances have been made in the science of radio communication, and in particular the utilisation of frequencies in the very high frequency (V.H.F.) band has considerably broadened the scope of radio communication for industrial use.

Until recent times the use of V.H.F. radio communication has been largely confined to such bodies as the Armed Services, Police, Posts and Telegraph Departments and Fire Services, but as a result of the International Telecommunications Union Conference held at Atlantic City in 1947, a number of frequency channels has been allocated for industrial and other private uses throughout the world, and there is no doubt that V.H.F. radio communication can play an important part in these fields in the future.

The application of V.H.F. radio communication can be divided into two main categories :—

(*a*) Mobile communication between a fixed point and units installed in cars, ships, aircraft, etc.

(*b*) Point-to-point communication between fixed stations to supplement or take the place of land lines.

In developed countries, mobile communication is the more important, allowing considerable scope for the application of new methods to problems which cannot be overcome by means of land-line communication. In undeveloped territories, where the construction and maintenance of land lines is difficult or costly, or where, for security reasons, a physical circuit is undesirable, there are many cases where V.H.F. point-to point radio offers the only practicable solution.

## ADVANTAGES OF USING THE VERY HIGH FREQUENCIES.

The very high frequencies are defined as lying between 30 and 300 Mc/s, and these have fundamental advantages over the lower radio frequencies. The range obtainable is limited and reasonably definite in extent—15 to 25 miles between a mobile unit and fixed station, 40 to 50 miles between fixed stations, depending on the type of terrain—the transmitter power required to cover these ranges is small, and a large number of frequency channels can be accommodated in the V.H.F. spectrum with sufficient spacing to prevent interference. These fundamental advantages make it possible for the licensing authorities to allow the use of V.H.F. by private industrial users. In addition, V.H.F. has other advantages as compared with the lower frequencies, which may be summarised as follows :—

1. There is a minimum of fading, and propagation is sensibly constant throughout the 24 hours, provided that the equipment is not working at the limit of its range.
2. As the propagation remains constant it is not necessary to change frequency to allow for varying conditions. This permits the use of fixed frequency equipment so that operation can be reduced to the same standard of simplicity as for a line telephone.
3. The small physical dimensions of the aerial systems involved enable highly directive arrays to be erected within a small compass.
4. The received noise level due to atmospheric and man-made static is low, resulting in a high level of speech quality.
5. Propagation is by direct radiation which is sensibly free from selective fading. This allows frequency modulation to be used for impressing speech intelligence on to the radio frequency carrier. This gives slightly greater ranges, together with a more constant signal over the service area and allows the design of smaller and more efficient transmitters.

Amplitude modulation is also used and has been standardised for some applications, such as air-to-ground communication.

## PLANNING A V.H.F. SCHEME.

According to the type of communication and facilites required, wide variations can be made in the design of a V.H.F. scheme to meet the exact requirements for a particular project. Three methods of working are possible : simplex, two frequency simplex, or duplex ; the correct

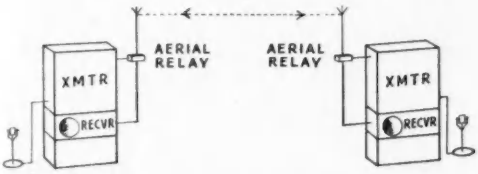


Fig. 1.—Simplex working.

type of control arrangement must be chosen to give the required facilities, and such factors as transmitter power, frequency, siting of stations and aerial height must be taken into consideration according to the range required and type of country in which the scheme has to work.

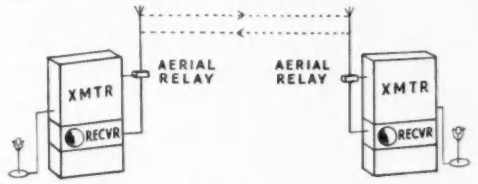


Fig. 2.—Two frequency Simplex working.

## METHOD OF WORKING.

### Simplex.

This is the simplest scheme employing a single frequency for transmission and reception so that it is necessary to switch the transmitter and receiver alternately on and off, and transfer the aerial when transmitting and receiving (fig. 1).

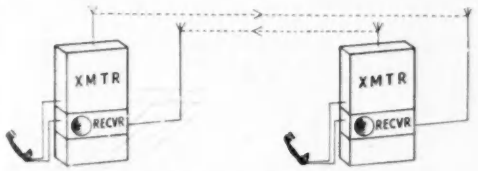


Fig. 3.—Duplex working.

The scheme has the advantage of complete flexibility as, if there are a number of fixed stations and mobile stations in a scheme, it is possible for any of the stations to communicate directly with any other provided, of course, that they are within the working range of each other. For mobile use the scheme also has the advantage that a minimum of battery power is used when operating the equipment. The disadvantage of the scheme is that a " press-to-speak " key must be operated while transmitting and so it is impossible to speak simultaneously in both directions. This can, however, be an advantage if there are a large number of stations within a scheme, as it leads to short factual messages rather than lengthy conversations.

### Two Frequency Simplex.

Where communication is required between a single fixed headquarters station and a number of outlying mobile or fixed stations, two frequency simplex can be used (fig. 2). With this scheme the transmitter and receiver are switched alternately as with single frequency simplex, but a different frequency is used for transmitting and receiving from the headquarters station. The scheme is particularly advantageous when it is desired to invest control entirely in the central headquarters stations, as it is possible for the outlying stations to hear a message from the central station although an outlying station may be transmitting.

It is possible for outlying stations to communicate with one another through the central station by connecting the receiver output to the transmitter input at the central station, but they cannot communicate directly. Where it is necessary to operate more than one scheme from the same headquarters station, or an adjacent headquarters station, the scheme has the advantage that the transmitter and receiver frequencies can be widely spaced to prevent interference from the transmitter of one scheme with the receivers of the other schemes.

### Duplex.

With duplex working (fig. 3) a different frequency is used for transmitting and receiving from the same station, and the transmitter and receiver are switched on at the same time. To achieve this it is necessary to have a separate aerial for the transmitter and receiver, spaced sufficiently to prevent interference, or alternatively to use a filter system to allow connection of the transmitter and receiver to the same aerial. The scheme has the advantage that operation is the same as with a line telephone and simultaneous two-way conversation is possible. For point-to-point links where linking on to a telephone exchange is required, this method of working

gives the most satisfactory arrangement, as exactly the same facilities can be provided as with a land line. For mobile working, the scheme has the disadvantages that the battery drain is slightly higher than with simplex and that the

Fig. 4.—The manager, Norfolk Sub-Area of the Eastern Electricity Board, using a remotely controlled Headquarters Station, communicating with engineers in the field by means of V.H.F. radio.

operation of the transmitter while receiving is in progress is likely to produce noise in the receiver by virtue of the radio frequency currents induced in the car chassis, and this may reduce the working range slightly.

## Methods of Control.

### Local Control.

Control can be arranged from a telephone instrument connected directly to the transmitter/receiver. This is the simplest arrangement but not always convenient in practice as it is often desirable to have a control point situated at some distance from the transmitter.

### Extended Control.

By means of multi-way cable it is possible to arrange control of the transmitter/receiver from a telephone instrument situated up to about 300 ft. from the equipment. Indication of a call is usually given by means of a loudspeaker arranged in the base of the telephone instrument which is automatically disconnected when the instrument is lifted and the receiver output transferred to the handmicrotelephone earpiece for normal operation.

### Remote Control.

It is often desirable to site a transmitter/receiver station at some high point in order to obtain the optimum propagation conditions and arrange operation from a point some miles away. By means of remote control equipment it is possible to operate the transmitter/receiver over a single pair of telephone lines up to a distance

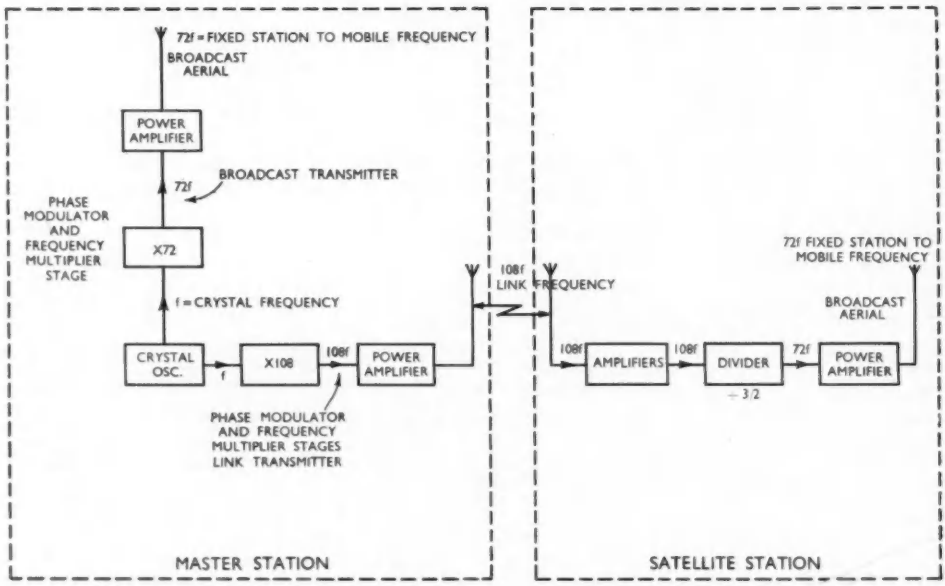


Fig. 5.—Schematic showing the principles of an area coverage scheme.

of 5 to 10 miles (fig. 4). It is also possible to arrange a V.H.F. radio link as standby to the telephone lines and to control the main transmitter/receiver over this link, should the telephone lines become faulty. Calling at the control point can be either by loudspeaker or by means of a bell which continues to ring until the radio call is answered.

### Telephone Exchange Matching.

Exchange matching units have been developed which enable a V.H.F. scheme to be connected on to any type of manual telephone switchboard so that any subscriber on the board can be connected to the V.H.F. link or mobile service. It is also possible to connect on to automatic telephone switchboards and to dial the required subscriber over a V.H.F. link.

### Selective Calling.

With a V.H.F. communications scheme involving a central headquarters station and several outlying fixed or mobile stations, it is sometimes a disadvantage for all the outlying stations to be disturbed by a call made to one of the stations. In this case selective calling can be adopted, whereby the headquarters station calls the particular outlying station required by dialling a number. This causes a bell to ring at the particular outlying station without any indication being received at the other stations.

Two types of selective calling have been developed—tone and impulse. With the simpler type the central station sends out a series of audio tones each of which corresponds to a tuned audio circuit at each particular outlying station. With the impulse type of selective calling the headquarters station sends out a series of audio pulses which step round selector switches at the outlying stations, each station being called according to the switch contact at which the selector comes to rest. Various special facilities are available such as the ability to call groups of stations as well as individual stations, and the ability to call all stations simultaneously when it is desired to circulate a general message.

### Area Coverage.

With schemes involving communications with a fixed headquarters station and mobile stations over a large area, it is possible that, due to the topography of the area to be covered, one headquarters station will not cover the entire area. The problem can be overcome by using a central headquarters station and a number of satellite stations connected to the headquarters stations by radio links. The frequencies of all the satellite transmitters are exactly or approximately synchronised to the main headquarters transmitter as reception will be possible over a wide area from several of the stations simultaneously. This has been achieved by controlling the radio link frequency from the headquarters station to the satellite stations by means of the main headquarters carrier frequency, and using the link frequencies in turn, to control the frequency radiated from the satellite stations.

Various refinements are necessary such as the provision of a delay network in the main transmitter to ensure that the radiation from each of the transmitters arrives at points in the service

Fig. 6.—Typical V.H.F. aerial installation in Malaya, showing vertically and horizontally polarised directional aerials mounted on a common mast.

area with the same phase relationship, and the provision of a mixer unit which selects the strongest signal received from the various satellite stations and suppresses the weaker signals with high noise content. A diagram illustrating such a scheme is shown in fig. 5.

### Choice of Transmitter Power.

The effective range of a V.H.F. station depends, among other factors, on the transmitter power, the signal strength varying directly as the square root of the transmitted power. However, the signal strength falls off more rapidly beyond the optical range so that the increase in range is by no means directly proportional to the increase in transmitter power. In general, there is a limit beyond which it is not economical to increase the transmitter power as the increase in range is slight, and a transmitter power of 100 or 500 watts is usually adequate for a fixed station used either as a central station in a mobile scheme or as a point-to-point link station.

For a mobile station, the limiting factor is battery consumption, and powers of 15 to 30 watts represent the maximum which can be obtained without undue current drain from the battery.

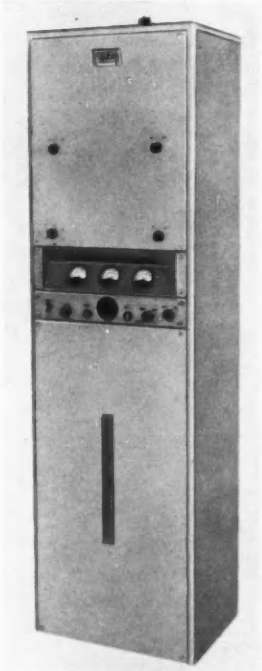

Fig. 7.—500 watt frequency modulated V.H.F. transmitter/receiver.

### Choice of Frequency.

The frequency channels in the V.H.F. band which have been allocated for the private user, lie approximately between 31 and 200 Mc/s. The choice of a particular frequency for a scheme is determined by the type of scheme, the range which is required and the restrictions placed on the user by the licensing authorities.

At the lower frequencies (i.e. 30-40 Mc/s), the noise level is higher than at the higher frequencies, but the attenuation beyond the optical path is less, so that slightly greater ranges are possible. At the higher frequencies the range becomes nearer to optical, but the noise interference from man-made static becomes lower.

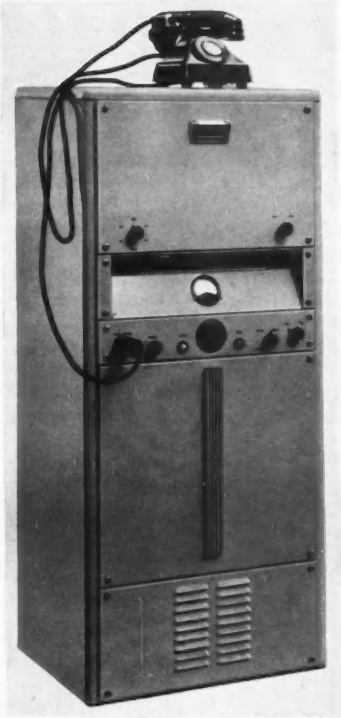

Fig. 8.—100 watt frequency modulated V.H.F. transmitter/receiver.

For mobile schemes where a fair degree of noise interference is likely to be encountered from the ignition system of cars, etc., the best frequency has been found from experience to lie in the region of 70 to 90 Mc/s. In this band the noise level is reasonably low, the range obtained is good, as these frequencies will bend appreciably beyond the horizon, and the aerial on the mobile units is conveniently small.

For point-to-point schemes using directional aerials, frequencies in the 70 to 90 Mc/s band are also convenient as they give a good range and the size of the directional array is not excessive. Where lesser ranges are required it is better to use a higher frequency so as to leave the lower frequency spectrum free for use with links requiring the maximum range.

### Choice of Site and Aerial Height.

The most important factors in obtaining the maximum range for either a point-to-point or mobile V.H.F. scheme are the choice of a good site and the erection of a high aerial. The range of the equipment is largely dependent on the distance of the optical horizon, and increases directly as the summation of the square roots of the aerial heights at both ends of the link. For point-to-point schemes a good aerial height at both ends of the link is desirable. For mobile schemes the fixed station aerial should be as high as possible in order to offset the low aerial height of the mobile unit. A typical V.H.F. aerial installation is shown in fig. 6.

A good V.H.F. headquarters site should be in as high a position as possible and the ground should fall away rapidly in the direction of propagation so that the effective aerial height in that direction is a maximum. If possible, the aerial should be higher than surrounding obstacles, but if this is impossible the aerial should be spaced as far away from the obstacles as can be arranged.

The maximum mast height which can be used depends on two factors : the cost of the mast and the length of aerial feeder which has to be used. Usually, for simple V.H.F. schemes, a mast height of 80 to 100 ft. is considered the limit, as with this height it is possible to use a single steel pole and the cost is low. With greater heights more complicated mast structures are required and the cost increases considerably. Also with the type of lead covered polythene insulated coaxial feeder usually employed for such installations, the feeder loss is such that it is not normally desirable to use feeder lengths of greater than 150 to 200 ft., and in general this corresponds to a mast height of 80 to 100 ft.

### Power Supplies.

The power supply for the fixed station equipment is normally arranged for a 200-250 volt or 100-120 volt, 50/60 cycle, A.C. mains supply, and in developed territories this is generally available. Where no mains supply is available, prime mover generators have to be used either of the petrol or diesel type. Where continuous service is required it is usual to provide standby generating equipment with automatic facilities allowing changeover from one generator to the other in the event of failure.

Where a 20 watt fixed station is required and there is no power supply available, the battery operated mobile equipment can be used as a fixed station. A prime mover battery charger is necessary and is usually arranged to switch itself on automatically after the battery has discharged to a predetermined level, and switch itself off when the battery is charged. An alternative method, if meteorological conditions are suitable, is to use a windmill battery charger.

Fig. 9.—20 watt single unit F.M. V.H.F. fixed station transmitter/receiver.

For the mobile equipment the car battery may be used if the car dynamo has a sufficient charging rate to keep it fully charged. Usually, however, it is necessary to fit a large capacity dynamo and large capacity battery either as an entirely separate supply for the radio equipment or as a combined car and radio equipment supply. Another method is to have a separate high capacity battery for the radio equipment which is removed and charged daily, or as operating conditions require.

## EQUIPMENT.

### Fixed Station.

Figs. 7, 8 and 9 show 500 watt, 100 watt and 20 watt transmitter/receivers which are suitable for fixed station use. All the transmitter/receivers have been designed for tropical use and are fitted with forced air ventilation and dust filters. The latter prevent the ingress of dust when the equipment is used under dry desert conditions, or the ingress of insects, rodents and snakes when the equipment is used under jungle conditions. The transmitters are all provided with facilities for metering the necessary stages. Provision is made for local

control for testing purposes or for any of the standard types of control previously described.

### Mobile Station.

Figs. 10 and 11 show a 20 watt F.M. V.H.F. single unit mobile equipment. The equipment comprises a transmitter unit, receiver unit and power supply unit suitable for either a 6 or 12 volt battery supply voltage.

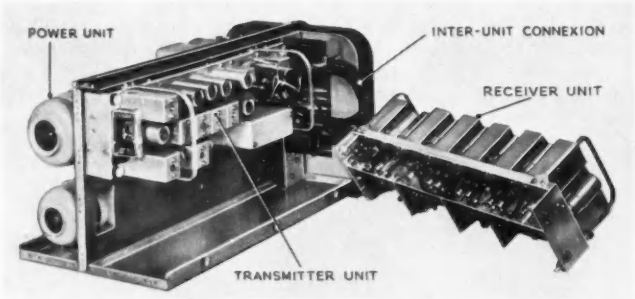


Fig. 10.—Construction details of the single unit mobile equipment.

The transmitter and receiver units are held by quick release fixings so that they can be readily removed for servicing, and replaced by spare units to obviate servicing delays. The apparatus is equipped with forced air ventilation and dust filters, the latter being even more important for mobile use than for fixed stations. Particular care has been taken with the design to reduce the size and weight of the equipment to a minimum by the use of miniature components and valves. To ease the problem of servicing and the stocking of spares, the number of different valve types has been reduced to three for the complete transmitter/receiver. Both transmitter and receiver are crystal controlled and include a facility for switching to an alternative crystal to give two channels spaced within 400 kc/s at the signal frequency.

The transmitter/receiver equipment is usually installed in the luggage compartment of a car or truck and connected by means of multi-way control cable to a controller situated in some convenient operating position (fig. 12). The controller incorporates a loudspeaker which is used for calling, and operation is from a handmicrotelephone which, in the case of simplex working, is fitted with a "press-to-speak" key.

### Pack Set Equipment.

A pack set suitable for carrying on a man's back or mounting on a bicycle is shown in fig. 13. The equipment comprises a transmitter with an output power of 0·25 watts, a receiver with a sensitivity of 1 $\mu V$, and power supply unit, complete with a 6 volt unspillable lead acid accumulator. The entire equipment weighs 24 lbs. and is arranged in a canvas carrying case. Special care has been taken in the design to make the equipment completely watertight, and the transmitter and receiver are mounted on rubber mountings to withstand shock. A telescopic aerial is fitted to the equipment, but provision is made to allow the connection of a separate aerial by means of a length of coaxial feeder to give greater aerial height and therefore increased range.

### Protected Mobile Equipment

For use on locomotives, coal cutters and ore handling plant, a more rugged type of mobile equipment is required with a greater resistance to shock, completely sealed against the ingress of steam or water, and with a sufficiently strong outer case to withstand the impact of heavy pieces of coal or ore. The equipment shown in figs. 14, 15 and 16 is used for this purpose. The cast outer case is completely sealed and acts as a heat exchanger to provide cooling for the mobile equipment. The actual equipment used is the 20 watt single unit mobile type mounted

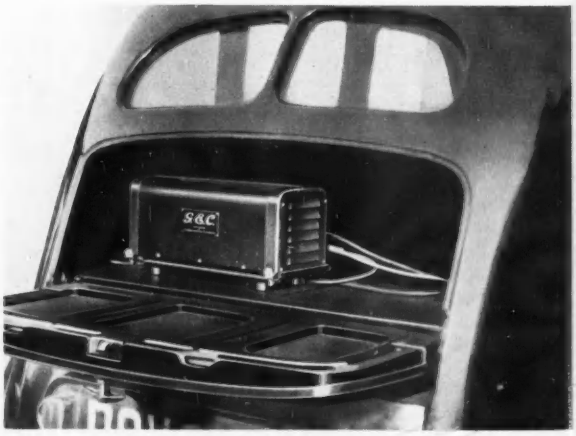


Fig. 11.—Typical mobile installation showing the transmitter/receiver in the luggage compartment of a car.

on a shock resisting tray which slides out of the exterior case to give access to the equipment.

The equipment illustrated includes a selective calling unit the operation of which has been previously described. Its use in this particular application is important, as bell calling is essential in view of the high noise level in the type of vehicle with which it is used.

It is designed for operation from either a 12 volt accumulator or from a 600 c/s A.C. supply, obtained by means of a low-pressure steam turbine connected to a locomotive boiler.

### Aircraft Equipment.

A single channel lightweight V.H.F. transmitter/receiver for use in aircraft is shown in fig. 17. The complete unit, which includes transmitter, receiver, and a 24 volt power supply unit, weighs only 8¼ lbs., and has a range of about 30 miles from a height of 10,000 ft. It is particularly suitable for use in small private craft and complies with A.R.B. standards.

### Multi-channel Equipment.

For point-to-point links, where more than two or three channels are required, multi-channel equipment can be used to give 7, 12 or 24 speech channels over one V.H.F. link. The multi-channel equipment is of the standard post-office type, using frequency division multiplex. The output is fed into a V.H.F. equipment with a sufficiently wide frequency response and low distortion to accommodate all the channels.

Fig. 19 shows a typical transmitter. It has a frequency range of from 70 to 88 Mc/s and the power output is 100 watts.

Where it is not possible to cover the desired range with a terminal at either end, an automatic repeater station is used which relays the multi-

Fig. 13.—Pack set adapted for use on a bicycle.

Fig. 12.—Mobile controller installed on the dashboard of a car.

channel carrier on another R.F. signal frequency without demodulating the incoming F.R. signal.

## APPLICATIONS.

### Civil Engineering and Large-scale Agricultural Projects.

For such large-scale engineering projects as hydro-electric schemes and the erection of large aerodromes in undeveloped territory, and agricultural projects such as the Ground Nuts schemes, V.H.F. radio communication has been used to provide the necessary communication from the time that the initial survey was made until the final complex communication network was installed.

### Survey Parties.

For carrying out surveys using triangulation points, V.H.F. com-

munication is ideal, as the nature of triangulation points makes them good V.H.F. sites, and with such sites on hill tops with clear views to other sites, ranges of the order of 50 to 100 miles may be obtained. For this use the single unit 20 watt equipment is suitable, mounted in a wooden transit case for transport by mule or by porters. The weight of the equipment is only 35 lbs., and even in a substantial teak carrying case this can be readily transported in rough country.

For the aerial equipment a light ½-wave dipole is used, mounted on a light steel or aluminium mast, 20 to 30 ft. in height. The power supply is obtained from a 12 volt accumulator which can be charged with a portable wind charger or small petrol electric generator.

**Mobile Communication.**

In commencing operations, communication may be required between a fixed station at the base camp and trucks working within a radius of 15 to 25 miles. For this type of work, a 20 watt or 100 watt headquarters station is installed in the base camp, either in a building or in a suitable control van, and the single unit mobile equipment installed in the trucks. Communication is possible while the truck is moving, or alternatively the truck can be parked and used as a communication centre. In the latter case a light portable aerial can be carried and, by erecting this on a light mast or in the branches of a tree, a greater service range can be obtained. When the truck is used as a communication point some form of calling device is usually required and a simple method is to arrange for the automobile klaxon to sound when a call is received.

Pack sets have also been used with advantage at this stage to enable personnel to communicate with the control van or with each other. The range obtainable between pack sets depends very much on the type of terrain, but in reasonably clear territory ranges up to 10 miles are possible provided that good sites are chosen.

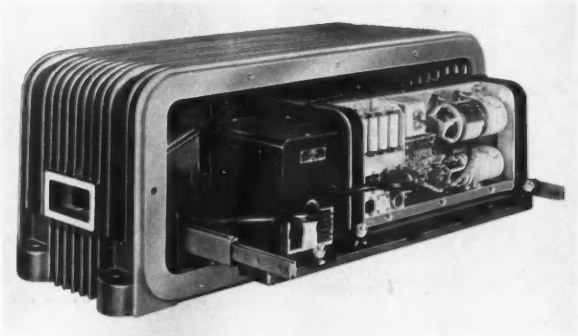

Fig. 15.—Protected type mobile equipment, interior view.

**Base Camp and Outlying Camps.**

When development of a project reaches the stage where there is a base camp and several outlying camps, V.H.F. can be used to provide communication between them. A single frequency simplex scheme is usually most suitable because of its flexibility, and battery operated 20 watt equipment is used for the outlying stations. In order to obtain a good range 80 ft. portable steel masts are erected and communication is possible over distances which will be determined by the type of terrain. In flat desert or scrub country ranges of the order of 40 to 50 miles are usual. In flat jungle country with heavy afforestation up to a height of, say, 150 ft. this range is generally reduced to the order of 20 to 25 miles, and it is desirable to site the stations in open spaces if possible. In hilly country the ranges will be entirely dependent on the siting of

Fig. 14.—Protected type mobile equipment.

the stations ; with the stations on top of hills ranges as great as 100 miles may be obtained, but with the stations in valleys the range may be reduced to a few miles only.

Fig. 16.—Controller for protected equipment.

Again pack sets are used for communication with the outlying camps by supervisors working within a radius of 5 to 10 miles from the camps.

**Permanent Communications.**

In many cases V.H.F. point-to-point duplex links are taking the place of telephone lines between important centres when a project is completed. The links can be connected to telephone exchanges and if more than one circuit is required between two points links can be used side by side. If many circuits are required multi-channel equipment can be used.

The use of V.H.F. links enables natural obstacles such as river crossings to be overcome, and if the territory is unsettled provides a more reliable means of communication. The experience gained using V.H.F. communication while a project is in progress makes possible accurate planning of the permanent stations and their sites so that the communications of the project can be planned as a progressive scheme from the beginning to the end of operations.

In addition to point-to-point links, mobile communication may also be of use in the final installation for such purposes as fire fighting and pest control.

**Electricity Undertakings.**

V.H.F. radio communication is finding an increasing use in this country by electricity undertakings, for mobile communication with repair gangs on transmission line systems and with maintenance engineers working on consumer distribution systems.

**Transmission Line Systems.**

For this application the headquarters station is controlled from the main transmission centre and contact maintained with repair gangs operating from trucks or vans. In order to cover a sufficient area, subsidiary fixed stations may be necessary at substations and these can be automatic in operation, controlled from the headquarters station or operated as entirely separate headquarters stations. Pack sets are also utilised to communicate between the repair trucks and personnel working on the line.

A further use for V.H.F. communication in undeveloped territories is found as a fixed point-to-point network between transmission line substations. Where violent storms are encountered which damage overhead lines this communication is invaluable, as normal line communication is similarly affected at the time when its use is most

Fig. 17.—Single channel aircraft transmitter/receiver.

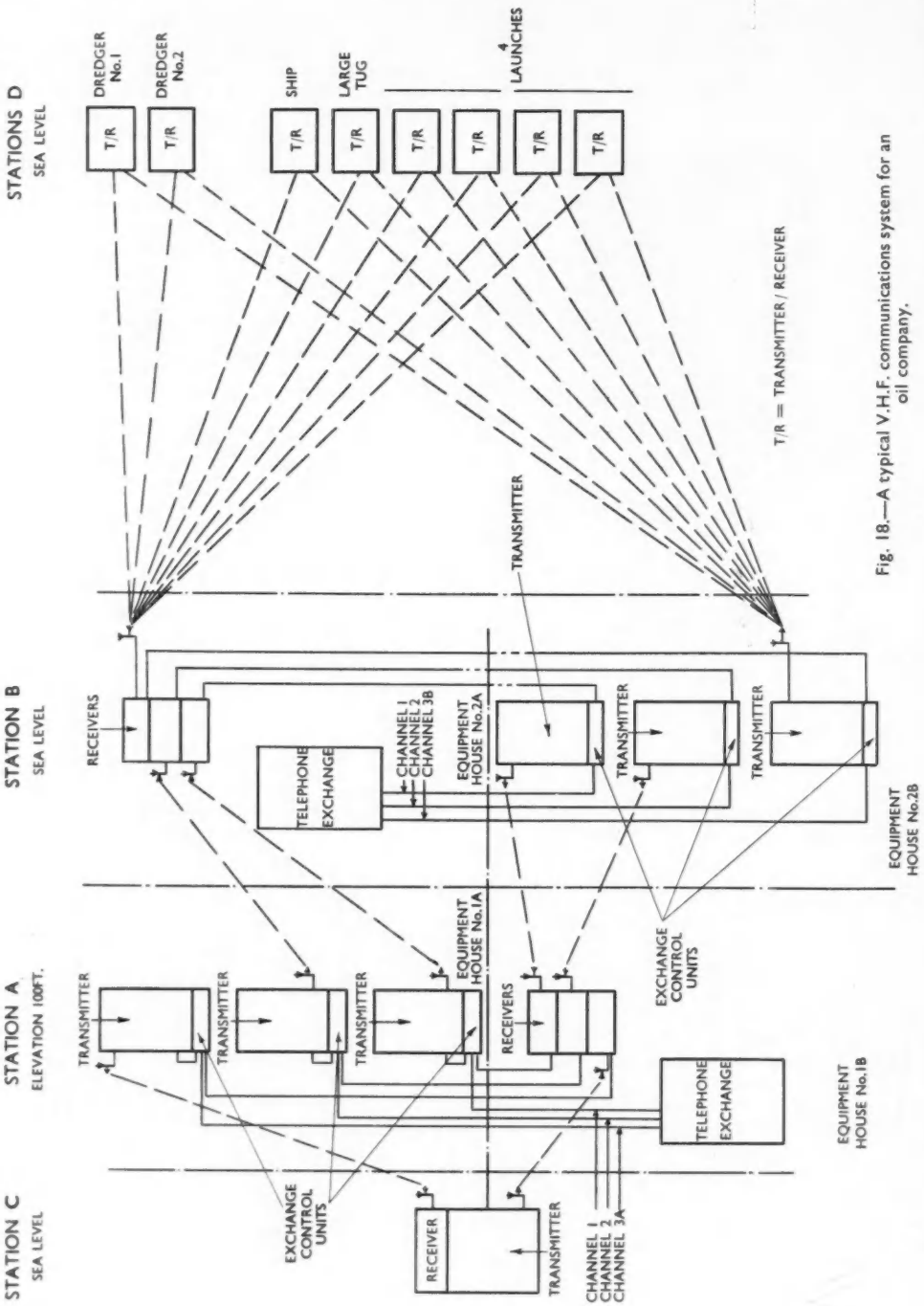


Fig. 18.—A typical V.H.F. communications system for an oil company.

ssential. V.H.F. point-to-point links can also e used for fault indication and switching by ieans of voice frequency signal impulses.

onsumer Maintenance.

For contact between service men on consumer naintenance a headquarters station is installed t the control point of the system and mobile quipment installed in the service vans. The dvantage of such a scheme is that it makes ossible the immediate mobilisation of service ersonnel at the required point in an emergency nd avoids lost time as the personnel can be outed in the most efficient manner. Another advantage is that difficulties can be reported immediately and advice given on the spot.

Forestry Departments.

Where Forestry Departments are not too great in extent or are situated in hilly territory where long V.H.F. ranges can be obtained, V.H.F. radio communication offers many applications for routine patrol work and fire fighting. During the dry season the fire hazard is often predominant and it is necessary to establish look-out posts on high points to report fires immediately. Such look-out posts make ideal V.H.F. sites as they overlook the territory and provide excellent headquarters stations for communication with fire control vans at the seat of the fire. With such a communication system, a saving of many thousands of pounds a year may be possible, not only by virtue of the reduction in damage to the forest brought about by the increased fire-fighting efficiency, but also because the labour force required to fight the fire can be recruited only when really necessary and directed to a place where it will be of most use.

In addition to fire control vans fitted with 20 watt mobile equipment, pack sets are used by patrolling foresters to maintain contact with the patrol van. For this purpose it is usual to equip the van with a portable aerial which can be erected on a high tree to give the maximum range.

If no power supply is available at the look-out post, battery-operated equipment can be used together with a petrol generator or possibly a wind charger.

Dock and Harbour Authorities.

By virtue of its restricted range and simplicity of operation, V.H.F. communication is finding increasing scope for communication between tugs and pilot vessels in harbours or on restricted sections of rivers. A typical installation of the 20 watt mobile equipment made for the Dundee Harbour Authorities, is shown in fig. 20. By means of a fixed control station in the Harbour Office, vessels can be routed more efficiently and full advantage can be taken of their position at a particular time as it is unnecessary for them to return to the office for each new assignment.

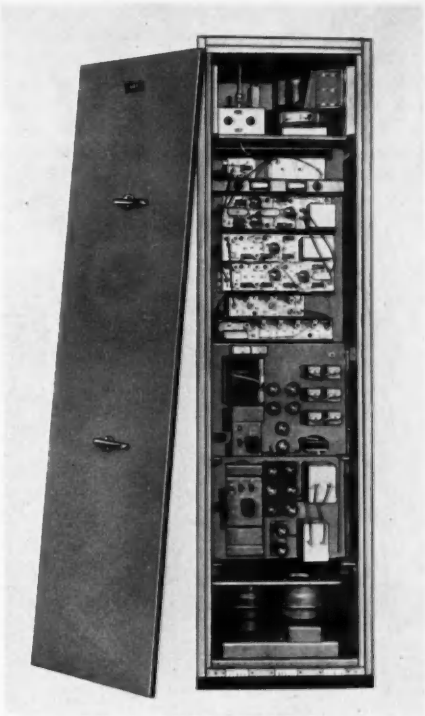

Fig. 19.—Transmitter for multi-channel working.

Another use is for a portable equipment which can be carried aboard visiting ships to maintain contact with the shore telephone switchboard. This method obviates the use of harbour submarine cables, the maintenance of which is both troublesome and costly.

Railways.

V.H.F. mobile equipment finds many applications for railway working and is particularly useful for communication between the signal box and shunting locomotives in large marshalling yards enabling operations to be carried out which would otherwise be impossible without highly elaborate signalling systems. Special problems are encountered when mounting equipment on locomotives, and with steam locomotives protected equipment is necessary. As the standard mobile equipment is fitted with dust filters, however, it can be used on diesel or electric locomotives without special protection.

### Steel Companies and Mines.

V.H.F. mobile communication can be used by steel companies for communication between mobile handling plant and the control station. Also it may be used on locomotives handling ore in a similar manner to that for railway marshalling yards. A description of such a scheme recently installed at the Corby Works of Stewarts and Lloyds, Ltd., has been described in the previous issue of this Journal.[1]

Fig. 20.—Two-way radio telephone communication in use in the wheelhouse of a pilot cutter of the Dundee Harbour Pilotage Authority.

### Oil Companies.

As oil companies often work in undeveloped territories there are many applications for V.H.F. radio which are becoming increasingly important. In addition to the various uses described under large civil engineering projects, there are special applications which are peculiar to oil company working :

(*a*) For communication with vehicles visiting oil wells and patrolling pipe-lines.

(*b*) For communication with experimental drilling points where it is not justifiable to erect a permanent telephone line as the drilling might not prove suitable.

(*c*) For communication along a pipe-line where reliable communication is absolutely essential in order that pumping pressures along the line may be correctly adjusted. This type of application can be extremely complicated and involve the use of multi-channel equipment to provide the necessary number of speech channels along the line and between important centres. Telemetering of oil pressures along the line is also possible by means of the V.H.F. link. Such a scheme is at present in the course of construction for a pipe-line in the Middle East, details of which have been given elsewhere.

(*d*) For communication between the shore and a vessel loading oil, so that pumping can be correctly regulated.

(*e*) For harbour communications to tugs and other vessels.

(*f*) For communication with aircraft operated by the company.

An illustration of a scheme recently supplied to an oil company is shown in fig. 18. The scheme provides for fixed point-to-point duplex communication between stations "A" and "C", also two separate channels between stations "A" and "B" with connection into a telephone exchange at both ends of the link and duplex communications with eight harbour vessels and station "B", with provision to connect the vessel communication links on to the main telephone switchboard.

### Conclusion.

The uses which have been found for the very high frequencies during the past few years are considerable, and in many cases the task of the project engineer has been eased by the new communication facilities which are placed at his disposal. The science is, however, a new one and rapid advances are being made which it is hoped will considerably increase the scope for new applications in the future.

[1] "Iron Ore Preparation Plant," by A. W. Leadbeater and Oliver Thomas, *G.E.C. Journal*, Vol. XVI, No. 3, July, 1949.

# Colour and Lighting

By G. T. WINCH, M.I.E.E., F.Inst.P., F.I.E.S.
G.E.C. Research Laboratories.

*The subjective and objective colour problems involved in the choice of colour-rendering properties of electric discharge lamps are outlined. Subjective chromatic adaptation effects are illustrated and a measure of correlation is shown to exist between the changes in subjective colour appearance and objective measurements of physical stimuli. Consideration is given to the visual and photoelectric methods of objective colour measurement used in the control of lamp manufacture and for the guidance of lighting engineers.*

*It is shown that the outstanding problem is the formulation of the factors which influence the user in deciding which objective colour-rendering characteristics are acceptable in various circumstances.*

## (1) INTRODUCTION.

THE progressive development of fluorescent and other electric discharge lamps and their increasing application in lighting installations, not only for utilitarian purposes, but also for recreational lighting in the home and elsewhere, has created a growing interest in the colour and colour-rendering properties of these lamps. Colour consciousness is increasing and is not limited only to the lamps, but also includes the coloured decorations and the whole aesthetic effect. This situation has naturally stimulated research into the factors which influence the choice of the colour-rendering properties of the lamps in conjunction with the colour and design of the decorations with which they will be used.

The ultimate decision as to whether the colour and colour-rendering properties of lamps are acceptable will clearly depend on the user's subjective appreciation of them in the particular surroundings in which they are used. The lamp manufacturer and lighting engineer who are responsible, respectively, for providing the lamps and designing the lighting installations are, therefore, faced with the following problems.

(*i*) The choice of the minimum number of "colours" of lamps to be manufactured which will provide acceptable colour rendering in the main classes of lighting application.

(*ii*) The control in manufacture of the colour and colour-rendering properties of the lamps to ensure uniformity in these characteristics to the necessary accuracy.

(*iii*) The design of lighting installations incorporating these lamps, which will be acceptable to the user in providing an appropriate level of illumination and colour rendering suited to the application, thus contributing towards the overall aesthetic effect.

These three general problems include associated detailed problems involved in the objective measurement of light and colour, together with an understanding of the subjective aspects of colour and their correlation with the objective measurements.

A very great deal of work has already been done towards the solution of these problems by specialists in the various fields of interest, which may not be familiar to many who have only a general interest in these subjects. It is the purpose of this article, therefore, to indicate the complexity of the problems enumerated above, to draw attention to the work which has already contributed towards the solution of many of them, and in the later sections to refer to some of the outstanding problems which are still under investigation.

## (2) SUBJECTIVE ASPECTS OF COLOUR.

Most of the subjective colour phenomena to which reference will be made have been known from the time of Helmholtz[1] since when there has been steady progress towards their understanding. Only comparatively recently has the work of Judd[2] and others shown that the subjective appearance of colours under different viewing conditions can be correlated with the objective colour measurement with a considerable measure of success ; these correlations will be dealt with in section (8).

STEEL COMPANIES AND MINES.

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The ultimate decision as to whether the colour and colour-rendering properties of lamps are acceptable will clearly depend on the user's subjective appreciation of them in the particular surroundings in which they are used. The lamp manufacturer and lighting engineer who are responsible, respectively, for providing the lamps and designing the lighting installations are, therefore, faced with the following problems.

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These three general problems include associated detailed problems involved in the objective measurement of light and colour, together with an understanding of the subjective aspects of colour and their correlation with the objective measurements.

A very great deal of work has already been done towards the solution of these problems by specialists in the various fields of interest, which may not be familiar to many who have only a general interest in these subjects. It is the purpose of this article, therefore, to indicate the complexity of the problems enumerated above, to draw attention to the work which has already contributed towards the solution of many of them, and in the later sections to refer to some of the outstanding problems which are still under investigation.

## (2) SUBJECTIVE ASPECTS OF COLOUR.

Most of the subjective colour phenomena to which reference will be made have been known from the time of Helmholtz[1] since when there has been steady progress towards their understanding. Only comparatively recently has the work of Judd[2] and others shown that the subjective appearance of colours under different viewing conditions can be correlated with the objective colour measurement with a considerable measure of success ; these correlations will be dealt with in section (8).

The subjective colour effects which must be taken into account in connection with the problems outlined in the previous section fall into two general categories. These are the temporary changes in colour appearance which occur immediately after the eye has been conditioned by having previously been in other differently coloured surroundings, or by artificial conditioning applied as in vision experiments. There are also the differences in the colour appearance of coloured objects which persist during observations, due to the simultaneous colour contrast of the adjacent and other parts of the surrounding field of view.

Examples of the temporary changes in colour appearance which occur due to conditioning of the eye just prior to observing are illustrated by the following simple viewing experiments which the reader may like to make. First view a sheet of white paper with both eyes simultaneously for about 30 seconds to ensure that they are similarly conditioned. If fig. 1 is now observed in quick succession, first by the right eye and then by the left, keeping closed the eye not being used, for most observers with normal colour vision the colour impressions received will be closely the same for each eye. If the left eye is closed and the right eye fixated on the black cross in the centre of the yellow area of fig. 2 for about 30 seconds, then immediately afterwards if fig. 1 is observed alternately by the left and right eyes, this time two very different colour impressions will be gained from the one picture. The eye previously conditioned by viewing the yellow area will see the picture in bluer tones and the general effect will be colder. If this experiment is carried out under light from tungsten filament lamps the appearance of the picture by the conditioned eye will be rather similar to that which would be normally observed when viewing the picture by daylight. This is because the eye has become fatigued by the yellow light so that all yellow and red colours will appear temporarily weaker. Repeating the experiment, but this time conditioning one eye by fixating it on the black cross in the centre of the blue patch in fig. 3, will make the picture in fig. 1 appear in warmer tones to the conditioned eye. If this experiment is carried out in daylight the picture will, for a short time, appear to the conditioned eye rather as it would when observed under incandescent tungsten light by an eye not artificially preconditioned.

In practice, colour appearance changes due to conditioning will normally occur in both eyes simultaneously and for this reason may be less obvious because in these circumstances the changes to different viewing conditions will generally be less sudden. They will be present, however, and will temporarily influence the subjective colours observed : for example, when passing from one room to another illuminated by lamps having different colour-rendering properties.

A further example of conditioning commonly experienced is that which occurs when colour-tinted sun glasses are worn. When they are first put on, noticeable colour distortion is present, but after a time the colours of familiar objects appear reasonably normal and acceptable, due to the chromatic adaptation of the eye. There is an apparent colour constancy of familiar objects such that white paper always appear white, green grass, green, geraniums red, etc., under illuminants widely different in their spectral energy distribution, or when observed through coloured filters which produce a similar effect. When the colour-tinted sun glasses are removed after having been worn for an hour or so, violent colour distortions will be apparent for some minutes until the chromatic adaptation of the eye has become normal again. This same general effect operates to a lesser degree by virtue of the chromatic adaptation resulting from the mixed coloured light from the objects in any room or scene under the particular form of lighting in which it is observed, but it may not be noticed because the change is gradual. This may be seen by observing fig. 1, first quickly with alternate eyes as in the first experiment to establish that it looks similar in colour appearance to both eyes. Now close one eye and observe the picture with the other for about 30 seconds, subsequently looking at it alternately with each eye in quick succession. The appearance of the colours will now be seen to be different to each eye.

The apparent increase in the saturation[3] of colours when viewed by an eye conditioned by light adaptation can be observed by first fixating one or both eyes on the cross in the centre of fig. 4 for about 30 seconds, and then quickly transferring to and fixating on the cross in the centre of fig. 2. For a short time the right-hand half of fig. 2 will appear to be less saturated in colour than the left-hand half, due to the part of the retina on which the right-hand side of the field is imaged having been conditioned by partial dark adaptation. The effect on other colours can be seen by repeating the experiment, but after conditioning, looking at fig. 1, when the colours in one half of the picture will appear to be more saturated.

These various conditioning experiments serve to remind the reader of the class of subjective

Fig. 1

Fig. 2

Fig. 3

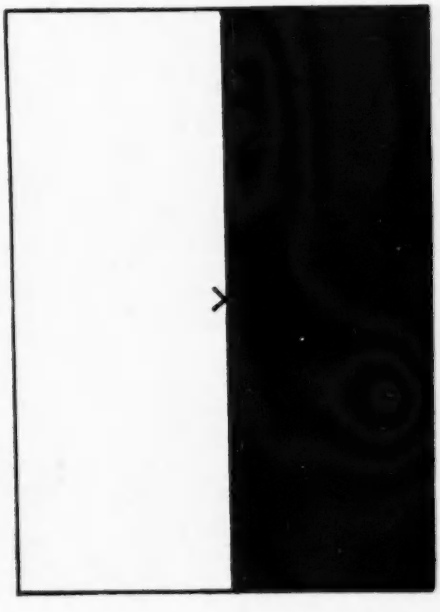

Fig. 4

Illustrations for demonstrating chromatic adaptation

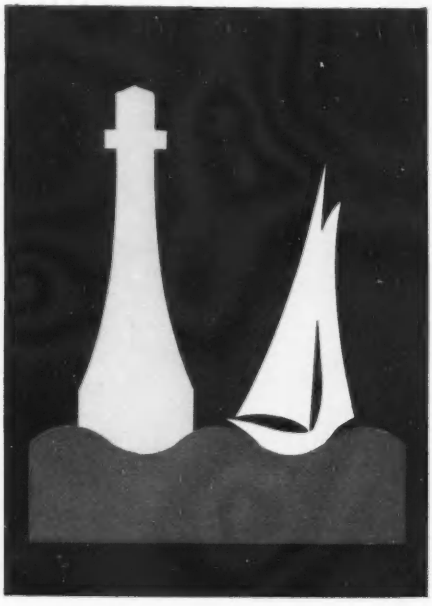

Fig. 5

Fig. 6

Fig. 7

Fig. 8

Effect of simultaneous colour contrast

Fig. 6

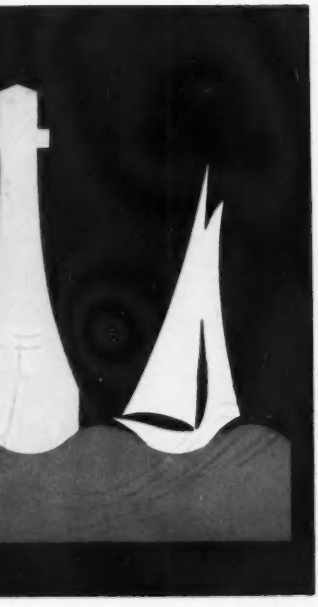

Fig. 8

phenomena, the effects of which persist only for a short time after conditioning, and, therefore, in general cause little embarrassment from the lighting design point of view. They may, however, affect an observer's judgment when forming opinions of the acceptability of different classes of lighting; for example, when comparing in quick succession installations using fluorescent lamps having different colour-rendering properties.

The class of subjective effect which is probably more important in its influence on practical lighting problems is that which persists all the time the coloured objects or pictures are observed, and is due to simultaneous colour contrast.

Examples can be observed in figs. 5, 6, 7 and 8 where the lighthouses, ships and sea are printed respectively in the same coloured ink in all four figures but where, because of the different colours of the surrounding field, in each figure the objects appear different subjective colours.

The above examples of the manner in which the subjective colours of objects change with viewing conditions, even although the physical stimulus remains constant, are an indication of the difficulties of measuring colour and assessing the acceptability of light sources of different spectral energy distributions when used in differently coloured decoration schemes.

The artist is aware of these subjective phenomena and part of his art is his ability to make appropriate allowance when painting his picture or designing his colour harmony scheme so that the effect will be aesthetically acceptable under the particular conditions of lighting and in the particular situation in which it will be seen.

The changes in subjective colour appearance, referred to above, can be measured in colorimeters with binocular viewing arrangements, as used by Wright[4] and others, where the conditioned eye observes one half of the colorimeter field, the other half being observed by the unconditioned eye. In this manner the subjective colour appearance may be measured in terms of objective colours by the visual colorimetric techniques referred to at the beginning of the next section.

### (3) OBJECTIVE ASPECTS OF COLOUR.

As has been seen, the colour sensations evoked by a coloured object or scene may be different under different conditions of viewing, even where the physical characteristics of the light entering the eye from the coloured object remain unchanged.

Fortunately, however, under any one strictly defined condition of viewing, the eye is able to judge to some precision when two adjacent coloured patches, with a sharp line of demarkation, appear the same colour, provided their photometric brightness is the same.

The ability to judge identity of colour, coupled with normal visual photometric techniques, has enabled a technique and system of colour measurement in the objective sense, to be built up. The objective colour of light is measured visually in terms of the proportions of light from three matching stimuli (i.e., coloured light sources), which when mixed and allowed to illuminate one side of an equality of brightness photometer field, will match in colour the light from the coloured light source under test which illuminates the other side of the photometer field.

Current developments in visual and photoelectric techniques, are referred to in a recent paper by the author[5] dealing with the measurement of light and colour, and it is not proposed, therefore, in this article to do more than indicate briefly the limitations of objective colour measuring techniques as they affect the problems enumerated in section (1).

In visual colorimeters, the matching stimuli may be any three convenient stimuli so chosen that a mixture of the light from any two will not match the third. The mixtures required to match a particular light source will, therefore, be different for different instruments, although they will be linearly related and results can, therefore, be transposed from one system to another for comparison purposes. The results obtained on any one instrument will, however, be dependent on the field size and field brightness, and the personal error of individual observers may be large if the spectral distribution of the mixture is very different from that of the test source. This latter error can be minimised by using a small 2-degree field of view, but the precision of measurement in these circumstances will be poor so that measurements need to be made by a large group of observers before a reliable mean result can be obtained. Donaldson[6] has shown that by using six instead of three matching stimuli the spectral energy differences can be so reduced that a large 15-degree photometer field can be safely used, thus greatly increasing the precision of colour measurement, at the same time keeping the personal errors very small.

An alternative method of visual colour measurement, not so widely used, is that in which the light from the test source is matched by a mixture of monochromatic light plus an appropriate admixture of white light and the results expressed in terms of the wavelength of the monochromatic light and the proportions of

the mixture with white light. Results on this system can also be transposed to the trichromatic systems.

Colour and eye spectral sensitivity measurements in the objective sense have established experimentally that light of one particular spectral energy distribution will be of one objective colour, so that the spectral energy distribution specifies uniquely the objective colour of a light source. Light of one objective colour can, however, be produced by a large number of spectral energy distributions.

To facilitate the comparison of colorimetric results obtained on different visual colorimeters, in 1931 the Commission Internationale d'Eclairage (C.I.E.) adopted a trichromatic colorimetric system for international use based on proposals by Smith and Guild[7]. This system, which is linearly related to visual systems, had a number of special advantages which cannot be detailed in the limited space available, and incorporates tables of figures defining the spectral characteristics of the C.I.E. Standard Observer, a hypothetical observer having colour characteristics closely related to the average of all human observers. From the C.I.E. Standard Observer data the objective colour of light in this international system can be estimated from the spectral distribution of the source, primary or secondary.

In recent years, physical colorimeters have been developed which enable objective colour measurements to be made directly in the C.I.E. system. This is achieved by means of photocells used in conjunction with colour filters, or other means of modifying their spectral response, thus realising in practice the three spectral distributions defining the C.I.E. Standard Observer.

A further advantage of one form of physical colorimeter which has been described by the author elsewhere[5, 8] is that, on the same instrument, measurements can be made on a light source in quick succession, of the C.I.E. chromaticity co-ordinates and tristimulus values, the luminous intensity or luminous flux, and the spectral energy distribution, either completely or in terms of the relative luminance in the eight spectral bands of Table 1. The instrument is also suitable for making the same type of measurements on light reflected from, or transmitted through, coloured media.

In 1948 at the C.I.E. meetings in Paris, the wavelengths intervals for the eight bands shown in Table 1 were agreed internationally for use in conjunction with the chromaticity co-ordinates for specifying the objective colour-rendering properties of an illuminant, with particular reference to tubular fluorescent lamps.

TABLE 1

| Spectral Band No. | Wavelength Limits | | Colour |
|---|---|---|---|
| 1 | 0·38$\mu$ to | 0·42$\mu$ | Far Violet |
| 2 | 0·42 | 0·44 | Violet |
| 3 | 0·44 | 0·46 | Blue |
| 4 | 0·46 | 0·51 | Blue-green |
| 5 | 0·51 | 0·56 | Green |
| 6 | 0·56 | 0·61 | Yellow |
| 7 | 0·61 | 0·66 | Light red |
| 8 | 0·66 | 0·76 | Dark red |

As indicated earlier, the objective colour of light is determined by its spectral energy distribution, so that the colour of light reflected from objects is dependent on the spectral energy distribution of the light source and the spectral reflection and/or transmission properties of the objects. As these latter are properties of the materials it follows that the objective colour-rendering properties of a light source are dependent on its spectral energy or luminance distribution. To measure the complete spectral energy distribution is for most purposes unnecessary and it is generally sufficient to make abridged spectral luminance distribution measurements in the eight spectral bands of Table 1.

In this general connection it should perhaps be mentioned that although the spectral luminance values alone, if sufficiently accurately measured, define the colour-rendering properties, only comparatively recently have physical measuring techniques reached the stage where such measurements can be made to high accuracy at commercial speeds. Due to the accuracy limitations of earlier apparatus used for this purpose, it was at that time found desirable to associate with the spectral luminance values the chromaticity co-ordinates of the light from the illuminant, or secondary light source. This is still current practice as colour-rendering specifications are in this form and in any case it is useful to know the colour of the illuminant as well as its objective colour-rendering properties.

### (4) COLOUR TERMINOLOGY.

In the past there has been some confusion of terms by the various groups of colour workers, but during the last few years considerable effort has been directed towards the establishment of an unambiguous colour nomenclature. Reports have been published by the Optical Society in America[9] and the Colour Group of the Physical Society in this country[10] which, apart from certain minor differences, are sensibly in agreement. These reports were discussed at the

C.I.E. meetings in Paris in 1948[11], with a view to reaching international agreement, but so far only a few of the terms and definitions have been agreed.

In these reports on colour terminology the subjective terms relating to sensation are grouped separately from the objective terms which apply to physical definitions of the stimuli. Throughout the present paper the terms used are those recently agreed internationally, or where no agreement was reached, those defined by the Physical Society (London) in their Report on Colour Terminology[10]. This latter report contains not only a list of the terms and definitions used in colour physics and the terms used in the various colour industries, but also co-ordinates them and makes recommendations for a preferred and unambiguous nomenclature. The artists' terms are also listed, but unfortunately no similar correlation of these with other terms was found possible. This is perhaps rather to be expected as, to quote the report, " for him (the artist) colour terms are ultimately of little use because the aesthetic values of a painting in terms of its colours are inherently incommunicable by means of speech."

### (5) CHROMATICITY SCALES IN THE C.I.E. OBJECTIVE COLORIMETRIC SYSTEM.

In the C.I.E. chromaticity diagram, fig. 9, the linear distance between plotted points of just perceptible difference in objective colour is very different in various parts of the figure, amounting to 20 : 1 in linear distance in extreme cases.

Unfortunately, no linear transformation of the C.I.E. system will produce a diagram in which minimum perceptible colour differences are uniform throughout the figure, but the linear transformation proposed by Judd[12] in 1935 gave an approximately uniform objective chromaticity diagram in which the maximum discrepancies from uniformity were reduced to 2 to 3 : 1.

MacAdam[13] in 1942 described further work which had been done to determine the limiting uniform objective chromaticity areas in the C.I.E. system and showed that they took the form of ellipses of different sizes and orientation, as shown in fig. 9. Moon and Spencer[14] showed that only a complex non-linear transformation can produce a diagram truly uniform in chromaticity.

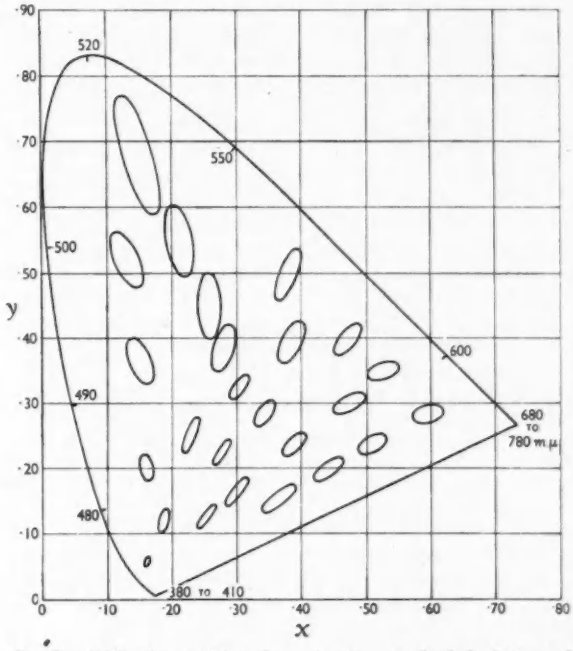


Fig. 9.—C.I.E. chromaticity chart showing standard deviations of minimum perceptible colour differences, represented five times actual scale. (After MacAdam, reference 13.)

### (6) FORMS OF OBJECTIVE COLOUR TARGET.

Targets for the objective colour limits used in specifications of tubular fluorescent lamps, and referred to in section (3), were originally[8] bounded by iso-mired lines [5, 8] drawn usually ±15 mireds (micro-reciprocal degrees) from the target centre, and these six-sided figures were rough approximations to MacAdam[13] ellipses of ± 5 m.p.c.d. (minimum perceptible colour differences). The trend towards closer colour control in manufacture and the increasing accuracy to which colour measurements can now be made at commercial speeds has made it desirable to base the limits on the actual MacAdam ellipse and for practical convenience to use a twelve-sided figure which closely approximates the ellipse and is easily plotted by routine operators from specified chromaticity co-ordinates.

### (7) OBJECTIVE COLOUR RENDERING AND APPRAISEMENT.

As indicated in section (3) the objective colour-rendering properties of an illuminant are related to its spectral distributions and are expressed in terms of the relative luminance in eight agreed spectral bands. Such spectral band data, together with the objective colour of the source expressed in C.I.E. chromaticity co-ordinates, provide a satisfactory method of appraising and controlling the objective colour-rendering properties of tubular fluorescent lamps in manufacture. With experience it becomes possible to judge from these data what will be the effect of small changes in spectral band values from some known objective colour-rendering properties, but as the differences become larger the difficulty of predicting the effect on the objective colour-rendering properties increases accordingly. The question arises, therefore, as to what additional information is necessary in order to facilitate the interpretation of the spectral band data from the point of view of its effect on the objective colour-rendering properties.

This is no new problem and in 1937 the author[3] considered the possibility of expressing objective colour-rendering properties by reference to the displacement in the Judd uniform chromaticity diagram of the plotted positions of a representative set of coloured surfaces or filters when illuminated by light from the test sources, as compared with some chosen reference source. It was felt that this might give a useful picture to the user of the manner in which objective colours would be distorted as compared with their colours under daylight or some other artificial reference illuminant. At that time, this proposed technique was not pursued because apparatus was not then available for quickly making accurate measurements of objective colour directly in the C.I.E. system. As has already been indicated, however, now that the type of precision photoelectric colorimeter and spectral band apparatus referred to in section (3) is available, interest may be renewed in this or a similar method of supplementing the spectral band method of specifying objective colour-rendering properties. It is evident that this would involve a large number of measurements on the objective chromaticity shift which occurs with the various present-day illuminants available, including the many types of fluorescent lamps, and these data are beginning to be accumulated.

### (8) CORRELATION OF SUBJECTIVE AND OBJECTIVE COLOURS.

From the previous sections it will be seen that adequate techniques have now been developed for measuring colour and colour-rendering properties in the objective sense and that even the changes in subjective colour due to conditioning of the eye before and during observation can also be measured in relation to the objective colorimetric systems and indicated in terms of shifts in the chromaticity diagram.

Judd[2] has made a very complete survey and summary of the published work on these relationships and has derived expressions which enable the subjective colour appearance to be calculated from the objective colour data for a number of viewing conditions. The hues, lightnesses and saturations calculated from these formulae are shown by him to be in fairly good agreement with visual estimates of subjective colour. Later work by Spencer[15] and also by Bouma and Kruithof[16], Hunt[3] and others find similar chromatic adaptation effects and some correlations with the objective measurements.

### (9) SUBJECTIVE COLOUR PREFERENCE.

It might seem at this stage that the three problems, indicated in section (1), which confront the lamp manufacturer and the lighting engineer, should be able to be solved by means of the techniques outlined in the foregoing sections. Unfortunately, this is not so as there is still one aspect of colour which has yet to be formulated, namely the factors which govern colour preference and the acceptability by the user of light sources of the various forms of objective colour-rendering properties in the many applications and situations in which they are required to be used.

Experience has in the past enabled some useful

progress to be made in this direction, and investigations into the possibility of a more exact solution to this aspect of the problem are being actively pursued. It is hoped that the results of some of the work at present in hand may be dealt with in a later issue of this Journal.

## (10) SUMMARY.

It is shown in sections (3) to (7) that in the objective sense, colour can be measured by visual techniques, and that photoelectric methods enable objective colour and colour-rendering properties to be measured accurately and rapidly in an international system which is related to subjective experience in a strictly limited sense. This relationship will only hold for the condition in which colours are matched in a small field of view at high brightness as in a visual colorimeter. These techniques can be used to measure, not only the objective colour of a light source, but also that of illuminated objects. Measurements of this class facilitate the control of the colour characteristics of fluorescent electric discharge lamps and enable specifications to be framed for ensuring uniformity of the manufactured product in this respect.

Due to the chromatic adaptation of the eye, however, as indicated in sections (2) and (8), the subjective colour appearance of objects will change with viewing conditions, and will also be affected by the conditioning of the eye before and during observations. The techniques which have been developed for measuring these changes by reference to objective colour measurements and the correlation of these objective measurements with the subjective colour for normal observers have enabled expressions to be derived from which the subjective colour appearance under some viewing conditions and with certain illuminants can be calculated with a fair measure of success.

Objective colour and colour-rendering data and a knowledge of the correlations between the objective measurements and the subjective colour appearance under various conditions of view are of guidance to the lighting engineer in designing lighting installations, as they indicate directly the objective colour-rendering properties of the lamps. An approximation to the average subjective appearance of objects illuminated by lamps so measured and classified, may in some cases be able to be derived if sufficient details are known of the conditions of view under which the installation will be observed together with the state of conditioning of the observers, assuming they have normal colour vision.

These objective colour data and correlations with subjective colour do not, however, indicate the extent to which, in any particular application and decoration scheme, the subjective colour rendering will be acceptable to the user.

The measurements and investigations in hand, referred to in sections (8) and (9), will, it is hoped, contribute towards the solution of this last problem, and will be dealt with in a later issue of this Journal.

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# Principle and Features of a New Dynamic Braking and Motor Control System for A.C. Winders

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*The fundamental principle of a new system of control for A.C. winders is described, with particular reference to dynamic braking. After summarising the characteristics of the induction motor, the author deduces the essential conditions which it is desirable shall be satisfied and shows how the scheme meets these requirements.*

*This system of control is being applied to four* 4,200 *h.p. winders now being built for a large South African gold mine.*

## INTRODUCTION.

LARGE A.C. winders are driven by slipring induction motors. For winding, the stator is switched direct to the 3-phase A.C. network, the current and torque being limited by a variable resistance of the liquid type, or by a contactor controlled set of grid resistors in the rotor circuit. For dynamic braking, D.C. is applied between two phase-terminals of the stator and the rotor resistor used as a variable load.

Dynamic braking is particularly attractive when used as described in this article as it affords a very precise torque control. It considerably reduces the waste of energy entailed with reverse power braking, and also the wear of the mechanical brake linings.

The control of the rotor resistance, which must safeguard the equipment against excessive torque and current during motoring, does not present any serious problems. Nevertheless, efforts have been made in this scheme to effect improvements in regard to reliability and optimum economy of operation. The main objective, however, was primarily to obtain improved performance of dynamic braking on which the more sensitive side of the winder operation depends. A particular difficulty was to reconcile some apparently conflicting conditions which must be satisfied in the relationship between the strength of the D.C. excitation and the value of the rotor resistance. The control of both D.C. excitation and rotor resistance is combined so that the driver operates only one lever, i.e. he does not control D.C. excitation and resistance independently. Furthermore, the control must be definite in its response to the driver's lever so that in no case can the torque decrease when it should increase with increasing travel of the control lever and vice versa. It is also necessary to avoid excessive D.C. excitation when a limited braking torque has to be applied for a prolonged period, such as occurs in rope and shaft inspection, when the motor must move slowly and consequently ventilation is very much reduced. In such circumstances the machine would probably run hot unless the D.C. excitation were appropriately restricted. The problem was, therefore, to evolve a system of control which interrelates the D.C. excitation with the rotor resistance in such a manner that the D.C. excitation can be restricted at low speeds for rope and shaft inspection, without forfeiting the necessary braking power which is required normally at the same low speeds when a loaded or empty hoist is approaching its decking position. The solution which is described in this article includes at the same time a method of driving and reverse power braking control which offers maximum permissible acceleration or deceleration under any conditions of load without relying on time mechanisms or current limiting controls for the safety of the hoist.

## FUNDAMENTAL CHARACTERISTICS OF THE INDUCTION MOTOR.

It will make the new scheme clearer if the performance of the induction motor is first

briefly recalled in its simplest form, and then compared with that which occurs during dynamic braking. Throughout this article magnitudes which are to be referred to another winding than the one to which they actually apply will be marked by a dash. Thus $R_2$ is the resistance per phase in the rotor circuit, but $R'_2$ is the rotor resistance referred to the stator winding.

The performance of an induction motor can be derived from its well-known equivalent circuit (fig. 1). All values in this diagram are referred to the stator winding.

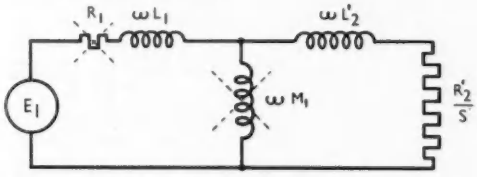


Fig. 1.—Equivalent diagram of the induction motor (referred to stator winding).

$R_2$ includes any external resistance that may be connected to the sliprings. $R_1$ is the stator resistance per phase. $X_1=\omega L_1$ is the stator leakage reactance, $X'_2=\omega L'_2$ the rotor leakage reactance and $X_{m1}=\omega M_1$ the magnetising reactance referred to the stator winding. All reactances are per phase and referred to the angular stator frequency, $\omega=2\pi f$. They are all constant, the only variable in fig. 1 is the equivalent rotor resistance $\frac{R'_2}{S}$ which varies because the slip $S$ varies with the speed

$$n = \frac{120f}{p}(1-S) \text{ (r.p.m.)} \qquad (1)$$

where $p$ is the number of poles of the motor.

The power which is transmitted to the rotor is $3 \times I'^2_2 \cdot \frac{R'_2}{S}$, $I'_2$ being the current per phase of a 3-phase wound rotor, referred to the stator winding. The mechanical power is obtained by deducting from this power the copper losses in the rotor circuit ($3 \times I'^2_2 R'_2$). Division of the mechanical power by the speed (equation (1)) gives the equation for the torque in lbs. ft. as

$$T=\underbrace{\cdot 176 \frac{p}{f}}_{\frac{7\cdot04\times3}{120}} I'^2_2 \frac{R'_2}{S} \text{ (lbs. ft.)} \qquad (2)$$

(since 1 watt = 7·04 lbs. ft. × r.p.m.)

The torque is proportional to the total power transmitted into the rotor.

An asynchronous motor—like any other apparatus which is used to transform energy from one form into another—has a well-defined maximum transmissible power. To this power limit corresponds the "stalling" torque of the motor. Generally the power which can be fed into a variable resistance reaches its maximum when the resistance equals the "inner impedance" of the "supply" to which it is connected. In the case under consideration this "inner impedance" $X_i$ is equal to the combined impedance of the network of motor and supply impedances referred to the terminals of the resistance $\frac{R'}{S}^2$. Since the impedance of the supplying mains network is usually negligible compared with the leakage reactances of the motor, it can—for the determination of $X_i$—be replaced by a short circuiting connection between the motor terminals so that $X_1$ and $X_{m1}$ appear paralleled in fig. 1 if the stator resistance $R_1$ is neglected for simplicity. It then follows that

$$X_i=X'_2+\frac{X_1 X_{m1}}{X_1+X_{m1}} \simeq X_1+X'_2 \qquad (3)$$

since $X_{m1}$ is large compared with $X_1$.

The maximum torque $T_{max}$ occurs therefore when

$$\frac{R'_2}{S_m}=X_i \qquad (4)$$

where $S_m$ is the stalling slip. The value of the maximum torque follows from fig. 1 (neglecting the stator resistance) as shown in Appendix I:

$$T_{max}=\frac{1}{34\cdot1}\frac{p}{f}\frac{E_r^2}{X_1(1+\frac{X_1}{X_{m1}})+X'_2(1+\frac{X_1}{X_{m1}})^2} \text{ lbs. ft.} \qquad (5)$$

$E_r$ is the rated line-to-line voltage.

The general torque equation can be written in the forms

$$T=\frac{2T_{max}}{\frac{S}{S_m}+\frac{S_m}{S}}=\frac{2T_{max}}{\frac{R_2}{R_{2m}}+\frac{R_{2m}}{R_2}}=\frac{2T_{max}}{\frac{R'_2}{S}\cdot\frac{1}{X_i}+\frac{X_i}{R'_2/S}} \qquad (6)$$

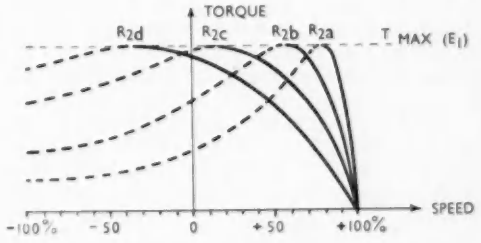


Fig. 2.—Induction motor characteristics with fixed rotor resistance $R_2$.

$R_{2m}$ is the resistance giving the stalling torque for any chosen value of $S$. Therefore the maximum torque is always the same for a given motor and the same applied voltage $E_r$, i.e. it does not vary with different resistances in the rotor

circuit. The resistance $R_2$ determines only the slip $S_m$ at which this maximum occurs. The resulting well-known variation of torque with speed for constant, but different, resistances $R_{2a}$, $R_{2b}$, $R_{2c}$, $R_{2d}$, is shown by the family of curves in fig. 2.

Each of these curves has been drawn in plain and dotted lines, the plain portion being the stable part and the dotted portion being the unstable part.

The unstable part of the characteristics must be avoided because, firstly, the torque increases in these portions with increasing speed, and,

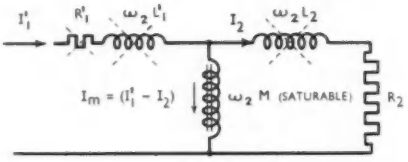


Fig. 3.—Equivalent diagram of the induction motor operating as dynamic brake (referred to rotor winding).

secondly, reduction of the rotor resistance leads to a reduced instead of to an increased torque.

Similar unstable portions also occur when the motor operates as a dynamic brake. The control is so arranged that these unstable parts of the characteristic are automatically avoided.

## CHARACTERISTICS OF THE INDUCTION MOTOR OPERATING AS A DYNAMIC BRAKE.

It will be found helpful in explaining the operation of an induction motor when functioning as a dynamic brake to use an equivalent circuit diagram which is comparable with that of fig. 1 for the induction motor. Such a diagram is shown in fig. 3. It differs from fig. 1 mainly on account of the different character of the "network impedance" to be introduced.

In this instance the circuit must be referred to the rotor winding in which there is a current $I_2$ of frequency $f_2 = \frac{np}{120} = \frac{\omega_2}{2\pi}$.

The stator current $I'_1$ when referred to the rotor circuit has the same frequency $f_2$ although it is actually D.C. if referred to the stator winding. The steady state value of this A.C. current is constant and is not influenced by anything that happens in the rotor circuit. This can be expressed in the equivalent circuit by assuming an infinitely large inner impedance of the supply circuit from which the excitation current is derived. It can be assumed that this current is driven through this large impedance by an infinitely large fictitious A.C. voltage. This condition is the opposite of that when motoring, where $E_1$, is constant and can be represented by a source of supply of negligible inner impedance.

$R'_1$ and $L'_1$ are, of course, negligible compared with the assumed infinitely large impedance of the fictitious supply system. The circuit defining the conditions for maximum torque and maximum power thus reduces itself to a simple connection of the magnetising reactance $\omega_2 M$ (referred to the rotor circuit) in series with the rotor leakage reactance $\omega_2 L_2$ and the rotor resistance $R_2$. The main effect of the apparently infinite impedance between the stator terminals of the motor is that contrary to the scheme of the A.C. motor in fig. 1 where the magnetising reactance $X_{m1} = \omega M_1$ had only a correcting and, for a first approximation, negligible influence on the inner impedance, this reactance now becomes the decisive factor compared with which the rotor leakage reactance is practically negligible. This is indicated in figs. 1 and 3 by the dotted erasure of the less relevant components.

First assume that $M$ is a constant reactance. Neglecting $\omega L_2$, maximum torque or braking power would occur at any speed if the condition

$$R_{2opt} = \omega_2 M \qquad (7)$$

is satisfied. The secondary current $I_2$ must in this case be constant with constant excitation $I'_1$. It then follows directly from fig. 3 that $I_{2opt} = \frac{1}{\sqrt{2}} I'_1$. The torque can be calcu-

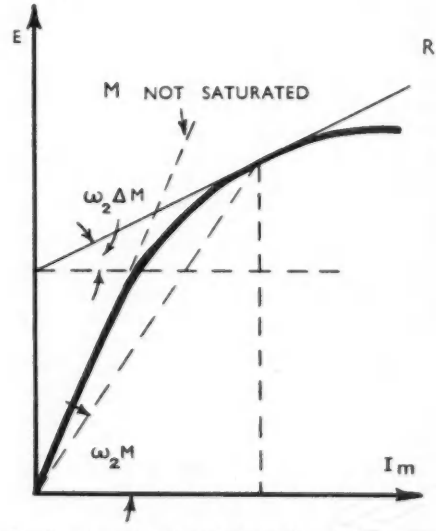


Fig. 4.—Magnetic characteristic of a winder motor.

lated as before from the ratio of power divided by speed. The maximum power in a 3-phase rotor must now be

$$P_{2opt}=3I_2^2 R_{2opt}=3I_2^2\,\omega_2 M=\frac{3}{2}I'^2_1\,\omega_2 M \quad (8)$$

and the corresponding torque, since $n=\frac{60}{\pi p}\omega_2$ (r.p.m.)

$$T_{opt}=\cdot 55 I'^2_1\,pM \text{ (lbs. ft.)} \quad (9)$$

The general character of the relationship between torque and speed of the dynamic brake must, therefore, be very similar to that of the

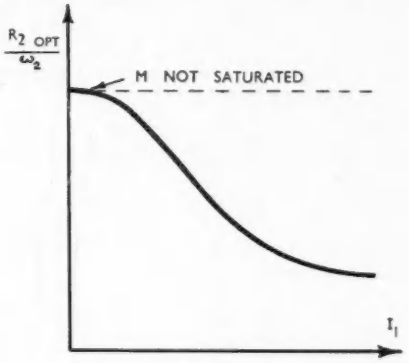


Fig. 5.—Relationship between D.C. excitation and optimum resistance to frequency ratio for dynamic braking.

induction motor. It is only necessary to consider speed instead of slip and the dominating influence of the magnetising reactance instead of the leakage reactances on the absolute value of the maximum torque available. Thus there is an optimum braking torque at some ratio of resistance over speed, and stable and unstable portions of the characteristic occur as before.

The problem is, however, complicated at this point because the magnetising reactance of the ordinary induction motor is so high that the unsaturated machine could not produce the braking torque required. This will be evident from the comparison between the magnetising current and the rated current giving the rated torque under normal conditions on the A.C. network. The magnetising current may be about one third of the rated current. Under the optimum conditions previously calculated for the unsaturated machine, the rotor current must equal the magnetising current. A machine excited by a primary D.C. current $I_1$ which just produces the normal magnetising current could, therefore, not develop more than about one third of its rated torque, whereas in practice about two-and-a-half times rated torque is required.

The calculation of the effective reactance, including the influence of iron saturation on the maximum value of the torque and its variation with D.C. excitation, will be found in Appendix II. The simple result is that, neglecting the rotor leakage, the inner impedance which determines the optimum braking torque can be expressed as the geometric mean of two reactance values, both of which are determined by the magnetic characteristic of the machine, i.e. they are functions of the magnetising current $I_m$. The one is the "total" reactance $\frac{E}{I_m}=\omega_2 M$ referring to the induced voltage $E$ and the magnetising current $I_m$, and the other is the "differential" reactance $\frac{dE}{dI_m}=\omega_2\triangle M$ referring to the slope of the magnetic characteristic at the point $E$, $I_m$. These characteristic reactances are shown in fig. 4. Their introduction gives the following expression:

$$R_{2opt}=\omega_2\sqrt{M\,.\,\triangle M} \quad (10)$$

The magnetising current bears a fixed relationship to the exciting current $I'_1$ only so long as the load resistance $R_2=R_{2opt}$, i.e. when the maximum torque which is possible with a given excitation is produced. This can be expressed by

$$I_m=\frac{I'_1}{\sqrt{1+\frac{M}{\triangle M}}}\ (R_2=R_{2opt}) \quad (11)$$

The relationship between $R_{2opt}$ and $I'_1$ which results from the arbitrary magnetic characteristic (fig. 4) is shown in fig. 5.

The maximum torque in lbs. ft. now becomes

$$T_{opt}=\frac{1{\cdot}1\,I'^2_1\,p\,\sqrt{M\cdot\triangle M}}{1+\frac{\triangle M}{M}} \quad (12)$$
$$(R_2=R_{2opt})$$

The general character of the torque-speed curves resulting with constant excitation $I'_1$ is still similar to that of the motor characteristics (fig. 2), i.e. for a given excitation the maximum value of the torque is constant and independent of the speed. However, the position of this maximum in the torque-speed diagram must be shifted to increasing values of the speed if the excitation is increased, but the resistance $R_2$ is kept constant. This effect is due to the iron saturation and is therefore unavoidable. The resulting curves are shown in fig. 6. The unstable portions of these characteristics which now occur to the right of the torque maxima overlap in a manner which permits neither a direct co-ordination between desirable rotor resistance and excitation nor between rotor resistance and speed of the machine. This effect reveals an essential factor in the known

difficulties which have been encountered in the past and which are avoided in this control scheme.

### THE PRINCIPLES OF THE NEW SYSTEM OF WINDER CONTROL.

From the foregoing analysis two simple results are derived :

(*a*) For every value of D.C. excitation current applied for dynamic braking there is a definite ratio between rotor resistance and speed which will give a constant and optimum torque which is independent of the speed (equations (10) to (12) ).

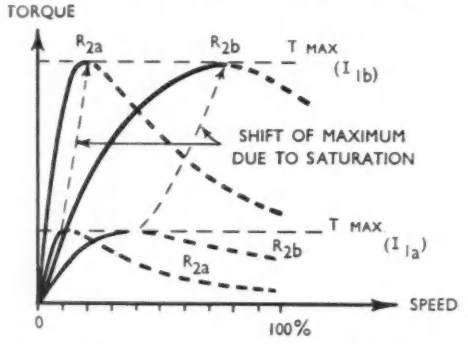


Fig. 6.—Dynamic braking characteristics with constant D.C. excitation and constant resistance $R_2$.

(*b*) The torque of the machine operating as an A.C. motor will be constant and independent of the speed if during motoring the rotor resistance is varied in constant proportion to the slip.

The second result follows directly from equation (2) since $I'_2$ is necessarily constant if the only variable $\frac{R'_2}{S}$, i.e. $\frac{R_2}{S}$ is kept constant. It can also be derived from equation (6).

These results have been translated into a practical solution of the problem in this control scheme. Since it is desirable to restrict the D.C. excitation current used during dynamic braking, the best solution is to control the resistance $R_2$ automatically in such a way that its value is always that at which the machine gives its maximum braking torque corresponding to any given excitation. This can be achieved simply by enforcing the automatic maintenance of the correct relationship between the current $I'_1$ and the ratio $\frac{R_2}{\omega_2}$. It will result in the lowest possible dissipation of heat in the stator whatever the operating conditions may be. Furthermore, operating at or near maximum torque minimises the effect of the relatively coarse steps of resistance in contactor-controlled grid resistors or of the variation of resistivity of the fluid in liquid controllers. The braking torque varies very little between consecutive resistance steps, but is steadily controllable by the D.C. excitation which can be made to vary smoothly so as to give a very fine and accurate braking control.

For driving or reverse power braking from the A.C. supply, it is only necessary to keep the rotor resistance at a fixed ratio to the slip and to provide means for controlling the value of this ratio. The motor will then run up with constant torque and constant current independently of speed and without the introduction of time delay or current limiting devices, the value of the torque bearing a definite relationship to the chosen position of the control lever.

### THE RESULTING SCHEME.

Fig. 7 shows a simplified schematic diagram of the control system based upon the foregoing considerations. In this diagram 2- or 3-phase connections are shown by single lines with double or treble dashes to indicate the actual number of connections. The reversing A.C. contactors and all interlocking and safety devices are also omitted. The co-ordination of the movement of the control lever with the operation of contactors and other control apparatus has been simplified so as to distinguish between the two different operations necessary for driving on the one hand and dynamic braking on the other, by moving the control lever in opposite directions. The practical adaptation of the scheme to any other kind of chosen relationship between the movement of the control lever and the desired control function is simple and is not dealt with in this article apart from the brief reference to a typical h-gate control in connection with fig. 9.

The control lever on the right-hand side of the diagram is shown as engaged through a quadrant to a vertical rack and control bar which indicates the three main functions of the control lever : it operates the contactors for energising the motor and auxiliary gear (centre), a variable ratio transformer *VT* (bottom) and the D.C. excitation control for dynamic braking (top).

#### MOTOR PERFORMANCE.

It may be easiest to explain first the sequence of operation for driving. When the control lever is moved to the left it forces the control bar downwards, thereby energising the " driving " contactor which connects the stator of the winder motor to the A.C. power supply. At the same time the auxiliary contact (*a*) on this contactor also closes and connects the sliprings of a small 3/2-phase control generator (operating

as a frequency converter) to the low voltage A.C. supply which is provided by the auxiliary transformer shown at the top of the diagram. The control generator is mechanically coupled to the winder motor either directly or through gearing. If directly coupled its number of poles must be the same as that of the main winder motor, but if geared an appropriately lower number of poles can be selected. The voltage induced in the 2-phase stator winding of the control generator will have the same frequency as that of the rotor of the main winder motor and its value will be proportional to the slip. This induced voltage is used to energise a voltage transformer $VT$, the tapping ratio of which is altered by the operation of the main control lever. The tapped voltage from the transformer $VT$ feeds one of the control coils ($RR$) of an electromagnetically operated oil servo through a variable resistance $r_1$.

The oil servo controls the main rotor resistance $R_2$ and the resistance $r_1$ in unison. Its function will be understood from the arrows indicating the action of the oil pressure $O_p$ from the pump and the direction of the return flow $O_{ret}$ of the oil. Thus the servo tends to raise both resistances

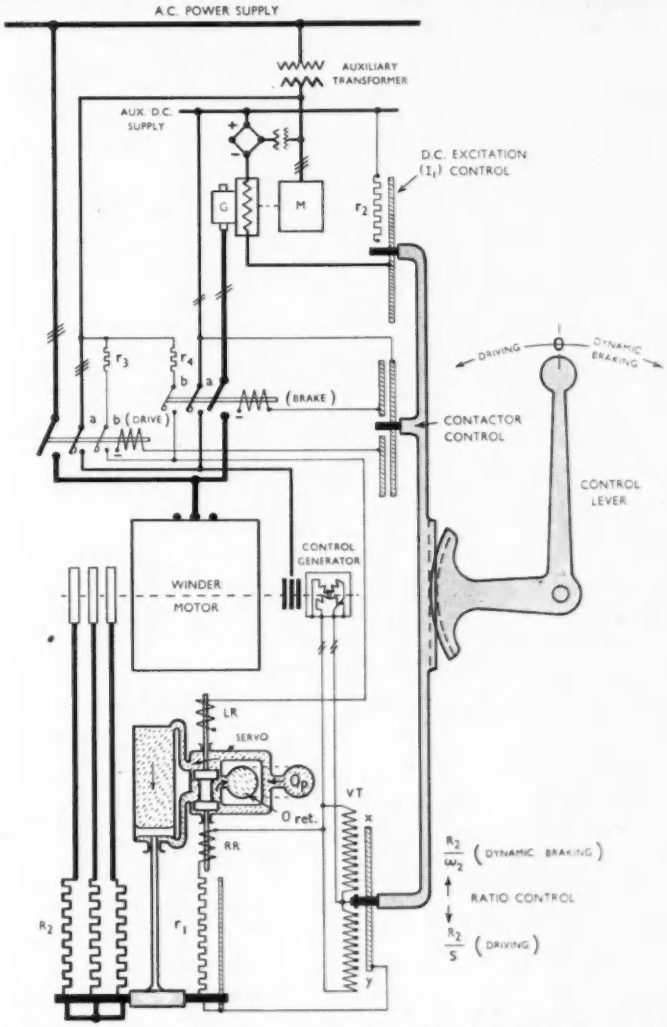


Fig. 7.—Schematic diagram of G.E.C. winder control scheme for driving and dynamic braking.

if the " Raise Resistance " coil (*RR*) is energised. It will also increase both resistances to their maximum whenever the valve is under the influence of its own weight only, so that the resistance $R_2$ will be maintained at its maximum value when all control excitation is cut off.

A second auxiliary contact (*b*) on the main contactor connects another control coil (*LR*) on the oil servo through the resistor $r_3$ to the constant low voltage A.C. supply. The current flowing in this coil is constant when the contactor is closed and produces a constant pull on the servo valve so that the oil servo tends to lower the resistances $R_2$ and $r_1$. Assuming that the resistance $r_1$ is so large that the constant pull of the " Lower Resistance " coil (*LR*) is stronger than the " Raise Resistance " coil (*RR*), the oil servo will reduce the resistance $r_1$ until its value equals that at which the current in the coil (*RR*) is just strong enough to balance the pull of the coil (*LR*). The valve will then take up the central position and the piston of the servo will come to rest. Since the current in the coil (*LR*) is constant the current in the coil (*RR*) at which this occurs must always be the same. Therefore, the resistance $r_1$ will be proportional to the induced voltage of the control generator, i.e. proportional to the slip.

The voltage tapped off the variable transformer (*VT*) is largest when the control lever is near its central position and is reduced with increasing travel of the control lever. If the lever is moved to the end of its travel, the voltage is not reduced to zero, as a residual voltage corresponding to the overhanging end *y* of the transformer winding is still applied to the coil (*RR*) and the resistance ($r_1$). This residual minimum voltage is the one that gives the lowest resistance/slip ratio and, therefore, the largest torque.

For simplicity, the circuit feeding the coil (*RR*) is shown as single phase in fig. 7. Actually it is 2-phase with 90 degs. phase displacement in order to produce a steady pull on the oil control valve even when the slip frequency of the winder motor and the corresponding induced voltage in the control generator pulsate so slowly that a single-phase control valve would follow the momentary values of the A.C. voltage.

The value of the resistance $r_1$ is chosen so that in any position of the servo the total resistance in the circuit formed by the voltage transformer and the operating coil (*RR*) is proportional to the resistance $R_2$ in the rotor circuit of the winder motor. This ensures that for any position of the control lever, not only the resistance $r_1$, but also the resistance $R_2$ will be kept proportional to the slip frequency of the winder motor. If, therefore, the control lever is kept in the same position while the motor alters its speed, the servo will adjust the value of the resistance $r_1$ continuously so as to keep the condition $R_2/S$ constant, but the value of this ratio will vary with the tapping ratio on the voltage transformer

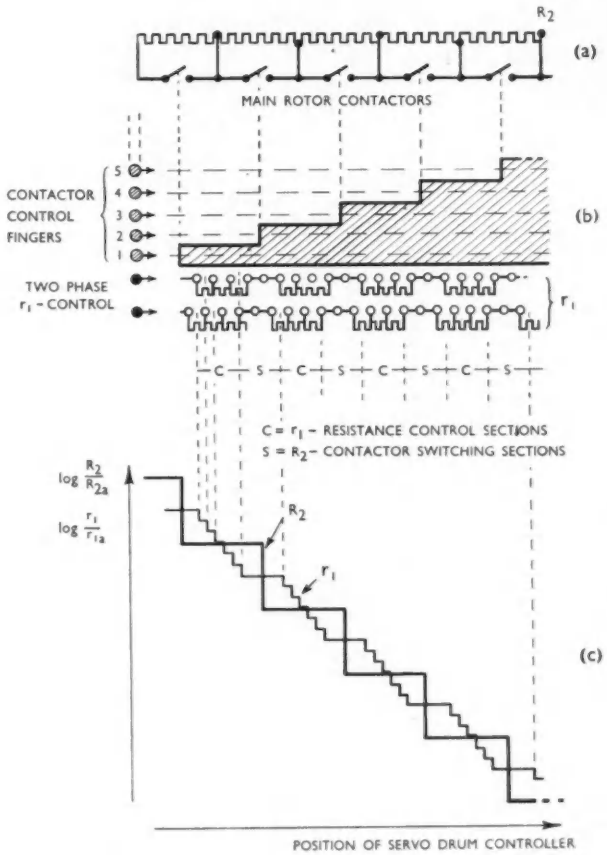


Fig. 8.—Schematic diagram of contactor control of grid resistors.

($VT$) in accordance with the lever position. The fixed relation between motor torque and lever position is maintained until the speed approaches synchronism when the motor torque falls off until it balances the load.

Obviously the operator can move the control lever as fast as he likes without danger of overstressing the rope. There is, on the other hand, no loss of time by delay mechanisms which must be set to meet the worst conditions and which are utilised for other schemes.

### Brake Performance.

The performance of the control system under conditions of dynamic braking is very similar. If the control lever is moved to the right thus raising the control bar (fig. 7), the brake contactor will be energised and connect the stator winding of the winder motor to the D.C. generator $G$ of the motor generator set. This generator is excited from an auxiliary D.C. supply, the field current of the exciter being controlled directly from the control lever through the resistance $r_2$.

The brake contactor also has two auxiliary contacts, one of which ($a$) connects the control generator to the auxiliary D.C. supply so that this generator is now excited with constant D.C. current through two of its sliprings, and therefore acts as an ordinary D.C. excited alternator, the induced voltage of which is proportional to speed.

This voltage again energises the "Raise Resistance" coil ($RR$) of the oil servo through a variable tapping on the voltage transformer $VT$ which is controlled by the lever as before. The only difference to the tapping control for dynamic braking is that the relationship between lever position and tapping ratio is different from that chosen for driving. This ratio control is adjusted so that the transformer tapping corresponds to the actual D.C. current fed into the winder motor in a manner which satisfies the relationship shown in fig. 5. The total variation of the tapping ratio required between the limits of lever movement is considerably less for dynamic braking than for driving and this is achieved by having a very much greater overhanging end $x$ of the transformer winding. In practice the same main tapping steps can be chosen for driving and braking so that although the voltage transformer is shown diagrammatically in fig. 7 as consisting of two different sections, one for driving and one for dynamic braking, there is in reality only one transformer per phase, a changeover of the overhanging sections $x$ and $y$ being made between driving and dynamic braking.

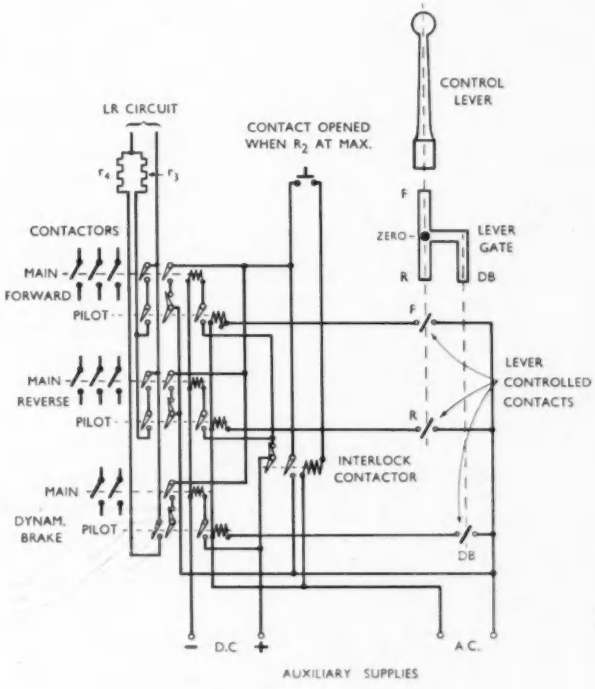


Fig. 9.—Brake-drive interlocking scheme.

The control mechanism will again provide a fixed relationship between lever position and torque exactly as when driving and constant torque will be maintained until standstill is almost reached.

The change from driving to braking can be made without the driver being subjected to restrictions of any kind. There are, however, a few safety measures introduced into the scheme which aim at reducing wear and tear wherever possible and avoiding the transient overload, which could conceivably occur under the extreme condition of the driver moving the control lever rapidly through the zero position.

### CONTACTOR CONTROL FOR GRID RESISTORS.

Unnecessary operation could occur if the servo oscillated slightly when adjusting the resistance $r_1$ to its correct value. Such oscillations are seen in the oscillogram, fig. 10, which was taken with an improvised test circuit.

Fig. 8 shows the scheme which is introduced for ensuring stability of main contactor operation. Resistance $R_2$ with its main rotor contactors is indicated in section (*a*). In this case the servo does not control the contactors directly, but through electromagnetic valves for pneumatically controlled contactors. These could be replaced by solenoids. The switching operation is effected by a drum controller actuated by a small servo of the Isenthal type. The method of co-ordinating the operation of the main contacts which actuate the motor contactors with that of the auxiliary contacts for varying the resistance $r_1$ is shown in fig. 8(*b*). Alternate sections *c* and *s* in the control movement of the servo are provided in which either resistance control (*c*) or contactor switching (*s*) takes place, these sections being so separated from one another that the controller cannot stop in the position where main contactor switching takes place.

The resulting relative variation of the steps of the rotor resistance $R_2$ and the control resistance $r_1$ is shown in a logarithmic scale in fig. 8(*c*). The corresponding progression of the resistance steps is geometrical. This not only ensures a constant residual variation of the main rotor current at each step, but also a constant variation of the control steps of the resistance $r_1$ on which the sensitivity to be chosen for the control mechanism depends.

This sensitivity of the control mechanism is kept constant by providing a constant current in the " Lower Resistance " coil (*LR*) of the oil servo ; i.e. this current has deliberately not been used for the major control (as theoretically it could have been) in order to arrive at a well-defined sensitivity in spite of the wide range of resistance control. However, a limited adjustment which may be different for driving and braking is provided by the separate resistances $r_3$ and $r_4$ shown in fig. 7. Resistors in this circuit may also be used for enforcing automatic or semi-automatic torque limitations of any kind that may be required, as for example, where acceleration has to be limited for winding men whereas maximum acceleration is to be applied for normal winding.

### THE BRAKE-DRIVE INTERLOCKING SCHEME.

The object of this interlock is to safeguard against any possibility of the A.C. contactor being closed before resistance $R_2$ has reached its maximum value. A large resistance in the rotor circuit at the moment when A.C. is applied to the motor is necessary because any shock application of torque must be avoided. On the other hand, the changeover from driving to braking should be as quick as is feasible, the only limitation being due to the normal " arc-interlock " on the main contactors. There is no danger of a shock dynamic braking torque because the magnetic delay which is inherent in the excitation circuit limits the rate of increase of the D.C. current.

The aim of the interlock scheme is, therefore, to delay only the energising of the A.C. contactors until the rotor resistance has reached its maximum value, and at the same time to leave the D.C. contactor free to close irrespective of the value of the rotor resistance. This is achieved by the scheme shown in fig. 9, which is supplementary to fig. 7 and shows all main contactors as well as their pilot contactors.

The closing of the main A.C. contactors can be prevented by the interlock contactor which is energised whenever a main contactor is de-energised by the opening of a pilot contactor, while the rotor resistance $R_2$ is not at its maximum value. This energising of the interlock contactor takes place during the transition period, when the pilot contactor has already opened but the main contactor is still closed. The interlock contactor remains energised until the contact at the end of the stroke on the control of the resistance $R_2$ has been reached.

Auxiliary contacts—(*b*) in fig. 7—which serve to energise the *LR* circuit are fitted on the pilot as well as on the main contactors. The interruption of the *LR* circuit by the main A.C. contactors prevents the *LR* circuit from being energised before the resistor $R_2$ has reached its maximum.

### REGENERATIVE BRAKING.

The weight of the rope is so great in many hoists operating in deep mines that an appreciable amount of energy must be dissipated during the second half of each run, when the weight of the rope and cage moving downwards is heavier than that moving upwards. This energy is usually wasted by dynamic or other braking being applied with steadily increasing force while the hoist is still moving at full or nearly full speed. It would be possible to avoid this waste of energy if regenerative braking were

used during this part of each run. The motor would have to be left full on with its speed slightly increasing beyond synchronous speed. This is permissible if the danger can be avoided of the hoist gaining too much speed during the transition period when the control lever has to be moved from driving (regenerative braking) to dynamic braking for final deceleration.

In existing control schemes the rotor resistance is first increased to its maximum and then reduced again to the value which is wanted for dynamic braking. With the proposed control and interlock scheme the resistance will not be increased immediately when the control lever is moved back from the " full on " position.

Only when the control lever has reached a position corresponding to a torque less than the positive or negative torque exerted at the motor will the rotor resistance $R_2$ begin to increase. With rated torque this is approximately midway between full-on and neutral positions. As soon as the lever is moved through the gate into the braking position, the brake pilot contactor energises the control circuit and the resistor $R_2$ is brought to the correct value that will give the chosen braking torque with a minimum of delay. For these reasons there is less tendency to overspeeding during the transition period between regeneration and dynamic braking.

### ALTERNATIVE FORMS OF CONTROL.

The relationship between torque and the position of the control lever, and the fact that movement of the control lever can be arbitrarily fast, make it possible to superimpose upon the torque control itself any overriding automatic controls such as may be desirable for speed or acceleration. The system should, therefore, be particularly suitable for fully automatic winders.

Taking as an example an overriding speed control, it would be very easy to subject the

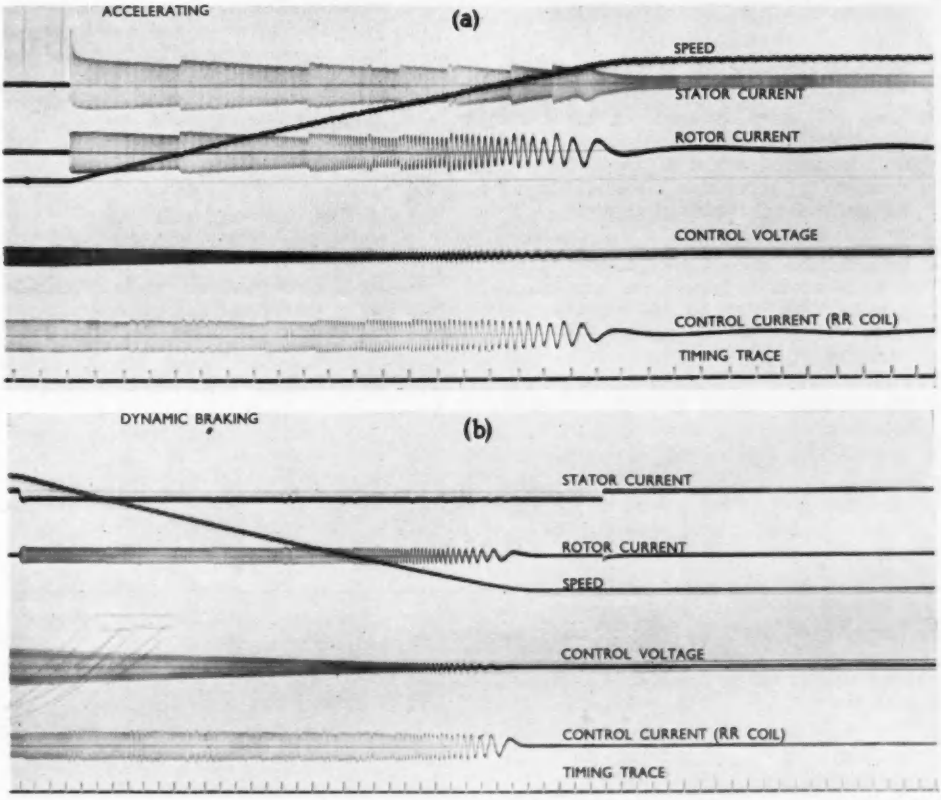


Fig. 10.—Oscillograms showing constant torque acceleration (driving) and dynamic braking performance of an experimental control equipment.

torque control to another servo which is in equilibrium only at a chosen speed. Thus if the speed were too low the torque would automatically be increased and reduced again as soon as the desired speed is approached. Such a scheme could be used to produce in an A.C. motor a performance which would correspond to that of a Ward-Leonard drive with overriding limitation of torque and current.

## SUMMARY OF THE FEATURES OF THE SCHEME.

The results obtainable with the control scheme may be summarised as follows :

1. A definite relationship between lever movement and torque is obtained under all conditions of operation. This is independent of speed for driving, reverse power braking and for dynamic braking.
2. It is impossible for the operator to exceed certain safe values of torque and current, however fast he may operate the control lever. This result is achieved without delay mechanisms or overriding current controls.
3. Long periods of dynamic braking at low speed, such as are required for shaft and rope inspection, result in the lowest possible rise in temperature of the main motor for any speed that may be chosen.
4. If any possible overstressing of the hoist by simultaneous application of both brakes is to be avoided, the definite relationship between braking torque and lever position makes it possible to combine the dynamic brake with the application of the mechanical brake in such a manner that the dynamic brake is released automatically as the mechanical brake comes into operation.
5. The operation of the dynamic brake near to or at maximum torque results in a very smooth control of the braking torque even if the rotor resistor $R_2$ is varied in relatively coarse steps. Also, it almost eliminates the influence of varying resistivity in liquid controllers.
6. The system can take full advantage of the torque of the motor when winding light loads so that any load can be wound with maximum permissible acceleration.
7. The maximum torque or acceleration can be limited by a simple mechanical stop on the control lever or by the setting of a resistance in the (*LR* coil) control circuit. Neither method will prevent the motor from running up to full speed provided that the set torque limit exceeds the load torque.
8. A quick changeover from driving to dynamic braking is possible without the rotor resistance first being increased to its maximum value. Thus the control minimises the tendency for the motor to gain speed if the torque is negative when the lever is moved from driving to braking. This should enable the operator to use regenerative braking during the major period of running at full speed with unbalanced load.
9. It is possible to make the torque or the rotor current independent of relatively large variations of the network voltage by the addition of a small voltage correcting transformer in the control circuit.
10. The scheme can easily be extended to satisfy various relationships between lever position, torque, speed or acceleration. Thus, for instance, the speed control of the A.C. motor can be made similar to that of a Ward-Leonard D.C. winder including current limitation with relatively few additions to the control equipment.

## APPENDIX I

A simple way of calculating the torque of the motor is by Thenevin's theorem. The open circuit voltage $E_i$ appearing across the terminals of the resistance $\frac{R'_2}{S}$ in fig. 1, if this resistance is made infinitely large, may be considered as the fictitious EMF of an equivalent circuit consisting of only the inner impedance $Xi$ [equation (3)] and the rotor resistance $\frac{R'_2}{S}$ in series. The current $I'_2$ flowing through this circuit is equal to the current through the resistance $\frac{R'_2}{S}$ in fig. 1.

$$E_i = E_1 \frac{X_{m1}}{X_1 + X_{m1}} \tag{1A}$$

if $E_1$ is the voltage per phase. The power transmitted to the rotor per phase is, therefore

$$\frac{P}{3} = \frac{E_i^2}{X_i^2 + \left(\frac{R'_2}{S}\right)^2} \cdot \frac{R'_2}{S} \tag{2A}$$

and the maximum power per phase with equation (4)

$$\frac{P_{max}}{3} = \frac{E_i^2}{2X_i} \tag{3A}$$

Combination of equations (3), (1A) and (3A) and introduction of the rated line-to-line voltage $E_r = \sqrt{3}E_1$ gives directly equation (5) since $T_{max} = 0{\cdot}176\frac{p}{f} \cdot \frac{P_{max}}{3}$ in analogy to equation (2). Equation (6) follows directly from a comparison between equations (2A) and (3A) since $\frac{T}{T_{max}} = \frac{P}{P_{max}}$

## APPENDIX II

The following relations hold with reference to fig. 3 if the secondary reactance $\omega_2 L_2$ is small compared with $\omega_2 M$.

$$E = I_m \omega_2 M = I_2 R_2 \qquad (4A)$$

$$I'^2_1 = I_2^2 + I_m^2 = \text{Constant} \qquad (5A)$$

The power $P = E \cdot I_2$ will be a maximum with varying rotor resistance if

$$\frac{dP}{dR_2} = \frac{dE}{dR_2} \cdot I_2 + \frac{dI_2}{dR_2} \cdot E = O \qquad (6A)$$

Differentiation of equation (2A) gives on the other hand

$$2 I_m \frac{dI_m}{dR_2} + 2 I_2 \frac{dI_2}{dR_2} = O \qquad (7A)$$

Combining equation (6A) and (7A) gives

$$\frac{E}{I_m} \cdot \frac{dE}{dI_m} = \left(\frac{E}{I_2}\right)^2 = (R_{2opt})^2 \qquad (8A)$$

$\frac{E}{I_m} = \omega_2 M$ is the magnetising reactance and $\frac{dE}{dI_m} = \omega_2 \triangle M$ is the slope of the magnetic characteristic as shown in fig. 4. Neither $M$ nor $\triangle M$ is constant, but both are defined by the magnetic characteristic of the motor, i.e. they are a definite function of the current $I_m$. The relation to be satisfied for optimum braking is, therefore,

$$R_{2opt} = \omega_2 \sqrt{M \cdot \triangle M} \qquad (9A)$$

and if this value is maintained it will be found from (8A) with (4A) and (5A) that

$$I_m = \frac{I'_1}{\sqrt{1 + \frac{M}{\triangle M}}} \qquad (10A)$$

$$(R_2 = R_{2opt}).$$

This proves that the magnetising current must be constant for a given excitation and that it is independent of the speed if $R_2 = R_{2opt}$.

The maximum torque resulting if equation (9A) is satisfied follows from

$$I_2 = \frac{I'_1}{\sqrt{1 + \frac{\triangle M}{M}}} \qquad (11A)$$

$$(R_2 = R_{2opt})$$

and gives for a 3-phase rotor

$$T_{max} = \frac{3\pi \times 7{\cdot}04}{60} p I_2^2 \cdot \frac{R_{2opt}}{\omega_2} \qquad (12A)$$

$$= \frac{1{\cdot}1 p I'^2_1 \sqrt{M \cdot \triangle M}}{1 + \frac{\triangle M}{M}} \text{ (lbs. ft.)}$$

It will be noted from a comparison between equations (10A) and (11A) that under the influence of saturation the secondary current $I_2$ is no longer equal to the magnetising current at the point of maximum torque. The limiting case for the unsaturated machine is correctly obtained by the transition to $\triangle M = M$ which then gives $I_m = I_2 = \frac{I_1}{\sqrt{2}} (R_2 = R_{2opt})$ in accordance with elementary considerations.

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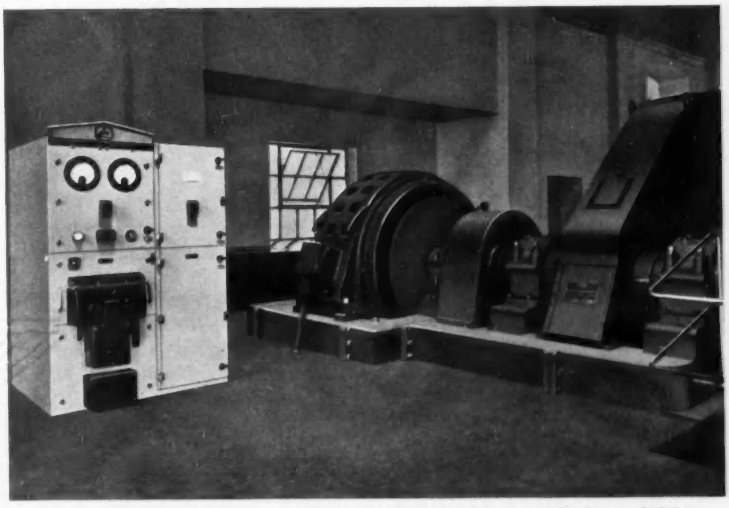
# A.C. Winder with Dynamic Braking



A geared A.C. winder, arranged for dynamic braking, installed at a Welsh Navigation unit of the National Coal Board.

# Vehicle-Actuated Road Traffic Signals

## APPLICATION TO A SPECIAL PROBLEM

By H. J. N. RIDDLE, A.M.I.R.S.E.
Siemens and General Electric Railway Signal Co., Ltd.

*Vehicle-actuated road signals have become established as a permanent feature on our roads, and experience over some fifteen years has shown that general principles outlined in this Journal twelve years ago were soundly based. New methods have latterly been introduced and this article brings the general picture up to date and describes one special application which is proving particularly useful at narrow approaches, bridges and wide crossings.*

### INTRODUCTION.

THE general principles of vehicle - actuated road signalling have been dealt with very fully in an earlier issue of this Journal.[1]

More than twelve years have passed since those articles were written, and it may be taken as an indication of the soundness of the operating principles then described that very little has been necessary since in the way of changes in design, and that no further major development has become evident. Concerning the Autoflex system of the S.G.E., the same basic principles are employed in the detection of vehicles by pneumatic mats and associated electro-pneumatic contact units, and the apparatus in the controller remains unchanged except that the timing circuits which determine the length of the Amber, Minimum Green, and Maximum periods now embody thermionic valves instead of the neon tubes referred to in Mr. Downes' articles. A short reference to, and description of, the Autoflex valve timer appeared in the pages of this Journal for January 1949.

Not only is it true that Mr. Downes' description covered the field very thoroughly, but, in addition, the Company has had the considerable satisfaction of finding that the Autoflex progressive system, as then described, would meet the specification for vehicle-actuated progressive equipment issued by the Ministry of Transport in 1938 —some two years after the system had been set in operation in several parts of central London. Practically all the equipment installed during and since 1935 (both at isolated and inter-connected crossings) is still working well, having been carefully maintained and wearing parts renewed where necessary.

The notes which follow lead up to one interesting use to which vehicle-actuated signals have been put to an increasing extent over the past ten years, and which was not given more than a brief reference in the previous articles. This is the signalling of traffic over narrow bridges or approaches. The facility involves an extension of the general principles described in the articles published in 1936, and for the benefit of those readers who may not have access to the older works it is intended to set out here the basic principles of vehicle actuation and to touch on the means employed in Autoflex equipment to bring them to effect, and after that to pass on to a description of the narrow-bridge schemes.

### BASIC PRINCIPLES OF VEHICLE-ACTUATED ROAD SIGNALLING.

The following rules govern the operation of vehicle-actuated signals as used in this country and in most places abroad.

#### General Arrangement and Terms.

(*a*) Traffic streams or "lanes" involved in a crossing controlled by signals are grouped as far as possible into lanes in which traffic may safely run at the same time; for example, the south-north north-south traffic at a simple cross roads will form one group, the east-west and west-east traffic the other. It has become customary to label these groups and the signals which give them right-of-way

[1] "Automatic Control of Road Traffic," by F. A. Downes, A.M.I.E.E., M.I.R.S.E. *G.E.C. Journal*, Vol. VII, Nos. 3 and 4, August and November, 1936.

with the term " phase " : the " A " phase, " B " phase, and so on.

(*b*) Signals are displayed to all traffic approaching the crossing, the signals of any one phase always displaying the same indication as all others for that phase.

(*c*) With a special exception, means are introduced to prevent the signals of any two

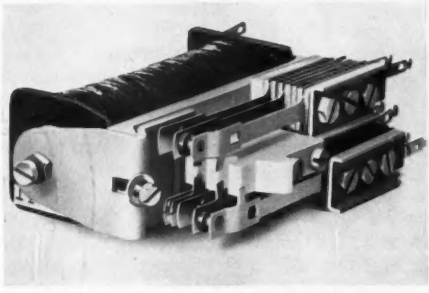


Fig. 1.—Autoflex lamp contactor relay.

phases showing green at the same time, even under fault conditions.

(*d*) Vehicle detectors are fitted in each lane at approximately the braking distance from the stop line associated with each signal. The expedient of placing detectors in some of the approaches only, has largely fallen into disuse, it being found that the saving in cost by such an arrangement is generally out of proportion to the resulting loss of traffic-handling efficiency.

(*e*) The change of signal indication as seen on any one signal face must conform to the colour sequence proper to the country in which it is used. In Great Britain and many other places this follows the sequence :

*Red*, changing to :
*Red with Amber* for 3 seconds, then
*Green*.
*Green*, changing to :
*Amber* for 3 seconds, then
*Red*.

It should be noted that the separate steps involved in this sequence are not correctly referred to as " phases ". The terms "Period " and " Moment " have been more properly used. " Phase " applies to any group of traffic lanes, and even groups of equipment associated therewith, in the same sense that a mains-supply engineer speaks of a switch or fuse being on one or other " phase."

PERFORMANCE OF SIGNALS SYSTEM.

(*f*) A vehicle running over a detector in the face of a red signal establishes a " demand " within the controller which will ensure that the right-of-way is changed in favour of this vehicle not later than the end of a predetermined period after the demand is registered. This period is called the " maximum green " period.

(*g*) The change requested under (*f*) above, will take place immediately the demand is registered, contingent upon two things :

(1) That the right-of-way (previously demanded by a vehicle on some other road) had been displayed for a short period called the " minimum green " period. The latter suffices to cover a vehicle which has to start from behind the stop line and to cross the intersection. It also ensures that pedestrians who may have started to cross the road at the previous transference of right-of-way will have time to make this crossing before the indication is again changed.

(2) That any " extension " registered by vehicles running under the existing right-of-way shall have expired see (*h*).

(*h*) A vehicle running over a detector in the face of a green signal secures an " extension " of right-of-way whereby the signal indication cannot be changed until the vehicle has had

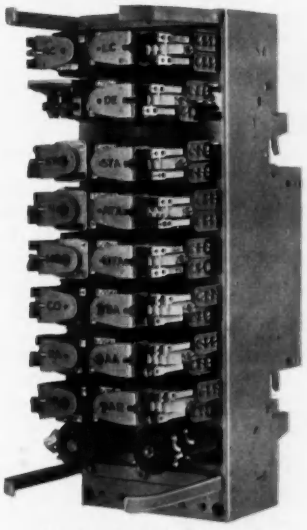


Fig. 2.—Typical relay set for a two-phase controller.

sufficient time to traverse the crossing. This condition is subject only to the possible expiry of the " maximum " waiting period on the other road (see (*f*) ).

From the foregoing it follows that the signal control mechanism must be capable of :

(1) carrying out the switching of right-of-way between the two or several " phases " in accordance with any one of the alternative national standard colour switching sequences.

(2) receiving an indication from detectors in the road, or roads, to which a red signal is displayed, and of interpreting this as a "demand".

(3) receiving a similar indication from a traffic lane to which a green signal is displayed, and of interpreting this as a request for the prolongation of that green indication.

The ultimate action at any one moment must depend upon these incoming " calls " conditioned by maximum and minimum green timing means.

In the Autoflex controller the whole of these interdependent functions is carried out by telephone type apparatus without the use of any rotating mechanism or heavy contactor gear. The telephone relay is, of course, well adapted to this requirement of co-ordinating several functions. By the substitution of the normal twin-tip contact springs with heavier gauge springs, carrying large single contacts of sintered silver-nickel, an excellent miniature contactor is provided which carries out the work of signal lamp switching. The signal lamp load may reach the value of 3 or 4 amperes at 240 volts where several signals apply to one traffic "phase." Fig. 1 shows one such lamp contactor. All other relays as seen in fig. 2, which shows a complete relay-set for a simple two-phase controller, are standard Post Office type telephone relays, their coils being wound for 50 volt operation. A power pack to provide direct current at this voltage can be seen in the complete three-phase controller shown in fig. 3, and here it should be noted that the main relay set, fig. 3(*a*), is nearly double the size of that shown in fig. 2. The reason for this is that a three-phase controller requires not only extra lamp contactor relays, Red, Green and Amber, but the inter-phase switching is much more complicated than in a two-phase controller. Thus each " phase " must be allotted its relays or relay contacts for switching the signal lights, and, in addition, others for switching in the timing controls applicable to each phase. Finally, other relays are needed to interpret the incoming detector calls and to route them appropriately to the demand circuits.

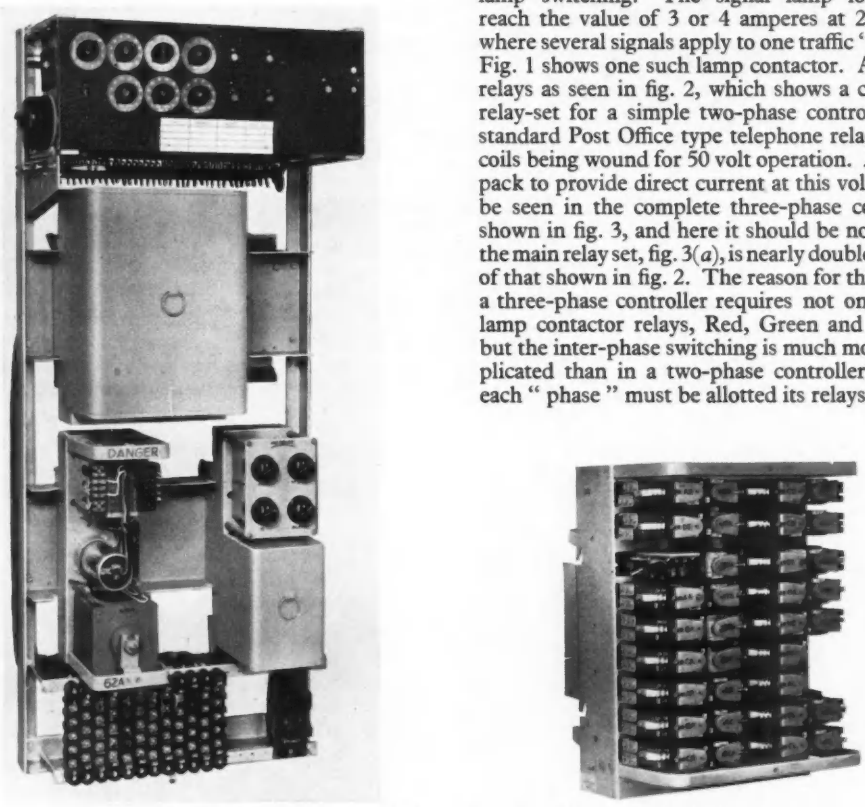



Fig. 3.—(*a*) Interior view of three-phase controller. (*b*) Detail view of main relay set of three-phase controller with cover removed.

### Detailed Circuit Operation.

To attempt to describe even a modest range of controllers, say, two-phase, three-phase and four-phase, would require far more space than is available, but it is felt that a detailed description of the operating circuits of a modern two-phase Autoflex controller will serve not only to show their nature, and that of the more elaborate members of the family, but also enable a comparison to be made with the corresponding circuits shown in Mr. Downes' article of thirteen years ago. when neon tube timing circuits were used. In the present circuits the thermionic valve has taken the place of

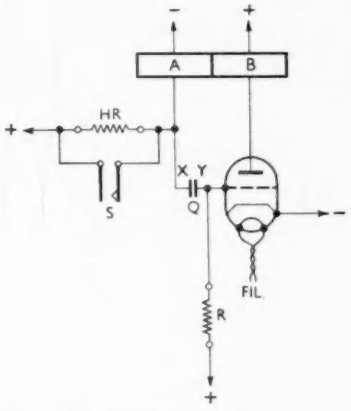



Fig. 4.—Diagram of the electrical circuit of the Autoflex neutralisation valve timer.

the neon tube, enabling the timing to be carried out at a working voltage of 50 instead of 300.

So far as possible, then, this circuit description follows that given in the earlier article.[1]

## TIMING CIRCUITS AND THEIR CHARACTERISTICS.

### The Fundamental Timing Circuit.

A circuit diagram of the means now provided in Autoflex controllers is shown in fig. 4. The simplest possible arrangement is given to help the reader to understand the general principle. In the actual controller, one timer may serve several purposes in turn, or for one reason or another be complicated by additional contacts. Further reference will be made later to the individual timers. The principle of operation is as follows :

Relay *AB* is energised at coil *A* upon the closure of the switch *S*, which also renders electrode *X* of condenser *Q* fully positive. The electrode *Y*, in consequence of its connection to the valve grid, is held substantially at cathode potential ; therefore the condenser becomes charged, electrode *Y* negatively with respect to *X*. To initiate a timed period *S* is opened, whereupon the potential of electrode *X* is reduced to the small voltage developed across coil *A* by the holding current through resistance *HR*. The electrode *Y* now holds the grid negative to the extent of the supply voltage, less the drop across coil *A*. The negative condition of the grid is progressively modified through the timing resistance *R*, and eventually it passes through a zero

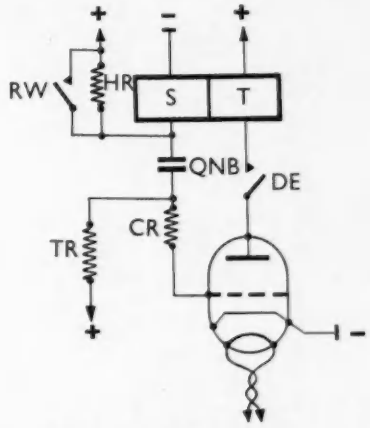



Fig. 5.—Basic speed-timing circuit.

condition allowing anode current to neutralise the holding flux in relay *AB* by its flow through the opposing winding *B*. The end of the timed period is signified by the release of *AB*.

### The Speed-Timer.

(Refer to the section " Basic Principles ", sub-section (*h*).)

The speed-timer circuit is shown in fig. 5. It is similar in principle to the normal timer, and the operation is as follows :

Contact *RW* is normally open and condenser *QNB* is free to assume a voltage on the grid side which is substantially zero due to the combined effects of the current through *TR* and the grid current which flows if the grid is even slightly positive, and in such circumstances the previously operated relay *ST* would release immediately contact *DE* closes. *RW*, however, is operated by vehicles traversing the detectors in the roads which have right-of-way, and upon the closure of its contact *QNB* will start to charge. The con-

[1] *G.E.C. Journal*, Vol. VII, No. 4. November, 1936, pp. 290-293 inclusive.

denser is prevented, however, from taking a full charge instantly, by the resistance *CR*. In fact, the amount of charge which is taken is now dependent upon the length of time for which *RW* is closed. Values of *CR* and *TR* are so chosen that the charge taken will have been modified to its zero value by the time the vehicle which had caused the actuation of *RW* has reached a predetermined point, or zone, at the crossing.

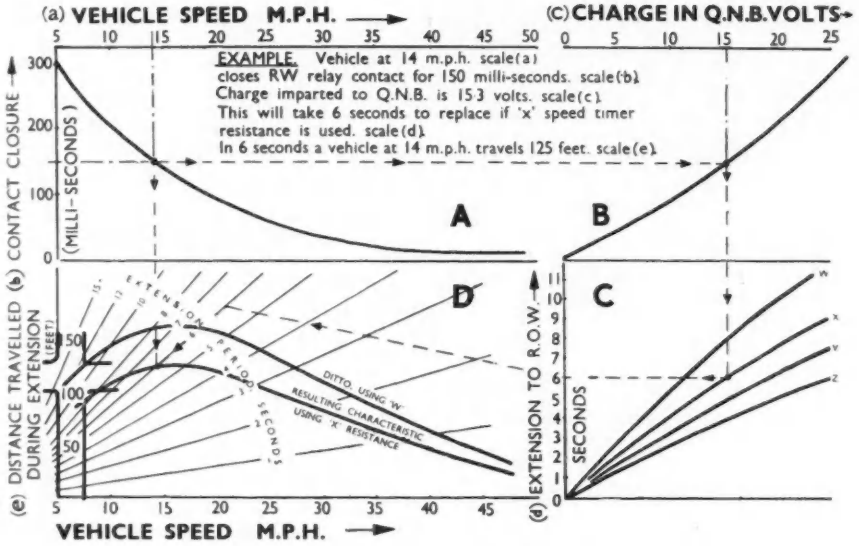

(a) VEHICLE SPEED M.P.H.
(c) CHARGE IN Q.N.B. VOLTS
EXAMPLE. Vehicle at 14 m.p.h. scale(a)
closes RW relay contact for 150 milli-seconds. scale(b)
Charge imparted to Q.N.B. is 15·3 volts. scale(c)
This will take 6 seconds to replace if 'x' speed timer
resistance is used. scale(d)
In 6 seconds a vehicle at 14 m.p.h. travels 125 feet. scale(e)
(b) CONTACT CLOSURE (MILLI-SECONDS)
A
B
C
D
(e) DISTANCE TRAVELLED DURING EXTENSION (FEET)
(d) EXTENSION TO R.O.W. SECONDS
DITTO, USING 'W'
RESULTING CHARACTERISTIC USING 'X' RESISTANCE
VEHICLE SPEED M.P.H.

Fig. 6.—Diagram of overall performance of the Autoflex speed-timer.

Contact *DE* is on the demand relay, and indicates by its closure that a vehicle, or vehicles, are calling for a change of right-of-way. A more detailed reference follows later.

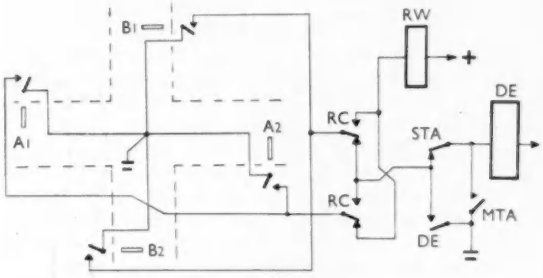
It is interesting to examine more closely the overall performance of the modern speed-timer and fig. 6 shows the four stages involved. Starting in section *A*, the duration of closure of the *RW* contact consequent upon the passage of vehicles over the relevant detector(s) can be read off the vertical scale (*b*) for any speed between 5 and 50 m.p.h. (This characteristic has been plotted from some thousands of observations, and is an average of these.) By transferring the contact closure duration into section *B*, the charge given to the condenser, and expressed in terminal volts, can be read off the horizontal scale (*c*). By referring this result downwards to section *C* the time required for the condenser voltage to be restored to zero can be read off from one or other of the four curves therein and the vertical scale (*d*). Each of the four curves in section *C* shows the performance for a different value of *TR*. Four such values are provided in Autoflex controllers to enable a selection to be made which will suit the layout of the signalled crossing. The result so far shows the extension given in seconds for any selected example. If this result is now transferred over to section *D* the distance travelled by the vehicle in the period to which it has given rise can be read on scale (*e*). The process may be repeated for any chosen speed, and an overall speed-timing characteristic plotted. The curves in section *D* are typical.

### Two-Phase Controller Operation.

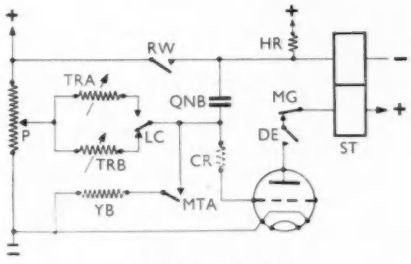
A series of diagrams is given in fig. 7 which has been drawn in simplified form to enable the operation of a simple two-phase controller to be followed. It should be borne in mind that these circuits while showing the essentials, have been stripped of all the ancillary circuits. The figure is divided into sections (*a*) to (*g*) and the small letters in brackets in the description of the circuits provide an easy means of identifying the particular relay or contact which is being referred to.

First it would be as well to run through the names and functions of the relays involved. They are :

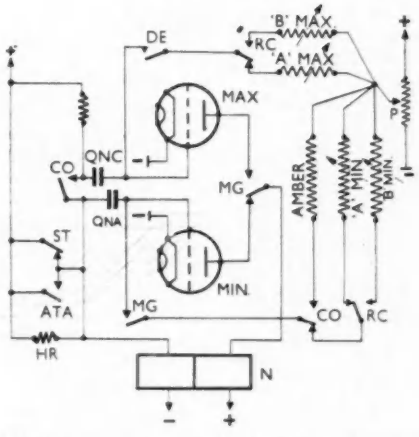
Fig. 7.—Diagrams showing in simplified form the operation of a two-phase controller.



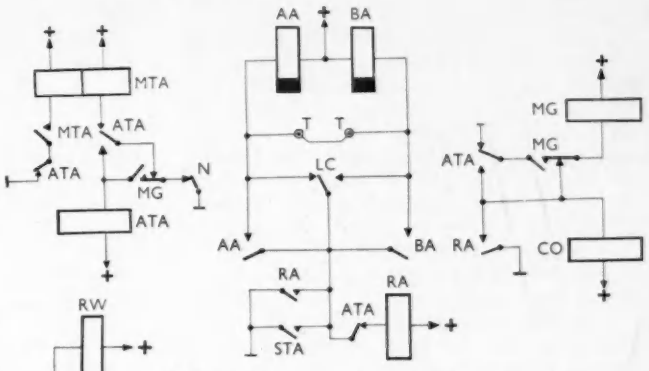

(a) Detector switching circuit.



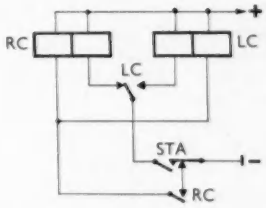

(b) Speed-timer.



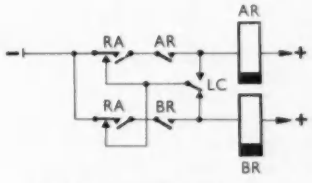

(c) Minimum green, amber, and maximum timing circuit.



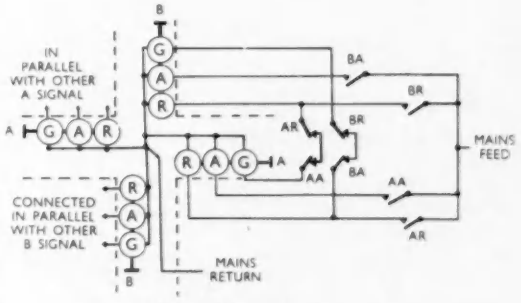

(d) Amber and associated relay circuits.




(e) Road and lamp control relay circuit.




(f) Red contactor circuit.




(g) Signal lamp circuit.

| *Name* | *Purpose* |
|---|---|
| *AA* | To illuminate the *A* phase amber lamps, and to ensure that the *A* green signal is not displayed at the same time. (At any rate this is so in the British colour sequence). |
| *BA* | The same in respect of the *B* phase signals. |
| *AR* | When de-energised illuminates the *A* red signal lamps, and prevents the illumination of the *B* green lamps. When energised, illuminates the *A* green signals. |
| *BR* | The same in respect of the *B* red signal lamps, etc. |
| *ATA* | A relay assisting in the switching of others at the end of every amber, minimum green and all-red period. |
| *CO* | Operated during a change of right-of-way to indicate this condition to various circuits. |
| *DE* | Operates when a vehicle traverses a detector in a road to which a red signal is being displayed, thereby recording a demand for a change of right-of-way. |
| *LC* | See *RC*. |
| *MG* | Indicates whilst in the energised position that a minimum green period is being timed off. |
| *MTA* | Operates when a vehicle has been kept waiting for the relevant maximum period, and thereby causes a forced signal change to take place. |
| *N* | The amber, minimum green, maximum and all-red timing relay. |
| *RA* | Indicates to various dependent circuits that an amber-with-red signal condition is in being. |
| *RC* | Together with *LC* indicates to detector and lamp and timing circuits whether right-of-way is in favour of *A* phase or *B* phase at any moment. |
| *RW* | Momentarily operated whenever a vehicle traverses a detector in a road to which the green signal is showing. It has the effect of holding the signal for that road at green for sufficient time for the vehicle to get close to, or through, the crossing. |
| *ST* | Closely associated with *RW* in carrying out the speed-timing function. |

The important relays *RW* and *DE* (*a*) are connected to contacts of relay *RC* in such a manner that they are switched to the detector contacts of roads *A* and *B* respectively, when relay *RC* is de-energised, and to the detector contacts of roads *B* and *A* when *RC* is energised.

*RW* (*b*) has a contact in the speed-timer condenser charging circuit which includes resistance *CR*, as already described, but even if any charges which had been impressed on the condenser have had time to be cancelled by flow through *TRA* or *TRB*, so that the grid voltage is substantially zero, the relay *ST* will not be neutralised unless the contacts *DE* and *MG* in the valve anode circuit are closed.

Upon a demand being received from a detector, relay *DE* (*a*) is energised and it then locks through contacts *DE* and *STA*. Contact *DE* (*b*) is now closed and connects the anode circuit in readiness for the neutralisation of relay *ST*. Another contact of *DE* (*c*) completes the timing resistance circuit for the maximum timer (condenser *QNC*.) Should no further vehicles operate relay *RW*, anode current will eventually flow, and relay *ST* (*b*) be released. Its relief relay *STA* thereupon becomes energised. On the other hand, if there should be a succession of vehicles causing the repeated operation of *RW*, and if they are so frequent that condenser *QNB* has no opportunity to display a zero voltage, no anode current flows when a demand closes contact *DE* (*b*) ; the timing process already shown to have been started in *QNC* will ultimately be concluded by the release of relay *N* (*c*), which in turn causes the operation of *MTA* (*d*). When this happens *MTA* (*b*) quickly discharges *QNB* via a comparatively low resistance *YB*, and immediately gives rise to anode current which releases relay *ST*. The relay *STA* then operates as already stated.

Contact *MTA* (*a*) will lock relay *DE* additionally, to ensure eventual return of right-of-way to the road from which it had been forced, the controller thereby " remembering " that it had stopped a stream of moving vehicles, the last of which may have passed the detector before halting at the red signal.

*ST* and *STA* having now released, and operated respectively, will cause the release of *DE* (*a*), unless *MTA* had been the cause of the signal change. This means that relay *DE* is ready to accept a further demand when such is registered.

Contact *STA* (*d*) operates relays *AA* and *BA* which hold over contacts of their own through *RA*, now closed. Contact *ST* (*c*) charges condenser *QNA* in preparation for the timing of the amber period.

Relays *RC* and *LC* (*e*) constitute a " pulse-halving circuit " where the effect of one closure of *STA* is to operate *RC* at contact *LC*. *RC* then locks at contact *RC* (*e*) until released by the opening of its locking circuit at *STA*, relay *LC* having operated via *RC* contact upon the restoration of *STA* after its first operation. The next reversal of *STA* opens the locking circuit for *RC*, and upon the restoration of *STA*, *LC* is also released. Actuations of *STA*, therefore, alternately operate and release *RC* and *LC*, and estab-

ish a sequence, *A*, *B*, *A*, *B*. In this way relays *AR* and *BR* (*f*) are energised alternately, providing the basis for switching right-of-way first to road *A*, then to road *B*, and so on. The lamp circuits are shown under the control of contacts *AR*, *BR*, *AA*, and *BA* (*g*). The further effects of contacts of *RC* will have been observed at *RC* (*a*) in the detector switching circuits.

The amber period initiated when *STA* first operates, is timed by the condenser *QNA* (*c*) which is afterwards recharged through contact *ATA* (*c*) upon the commencement of the next green period. Thereafter, in conjunction with relevant timing resistances, *QNA* times off the minimum green period. During amber periods, *QNA* is connected by contact *CO* (*c*) to the amber timing resistance, but is connected at all other times to the *A*, or *B* minimum timing resistances. It will be noted that the same relay *N* releases to terminate the maximum period in addition to those just mentioned. However, since the condensers *QNA* and *QNC* (*c*) may be timing different periods at the same time, they have to be separated and are, in fact, connected to separate valves called "min" and "max" respectively. At the end of an amber period relay *N* is released by current through valve "min", and operating *ATA* (*d*) releases *RA* at the break contact of *ATA*. *STA* now being de-energised, the amber relays *AA* and *BA* are released at *RA*. Also *ATA* energised at this juncture, re-operates relay *N* (*c*), and recharges condenser *QNA* as mentioned above. The relay *N* is, in fact, permitted to lie in the released condition for some 100 milliseconds. The minimum green relay *MG* (*d*) is operated at the start of the changeover period by *CO*, and it remains locked over its own contact until a further actuation of *ATA* occurs at the end of the minimum green period.

The controller now awaits a further demand from the road to which the red signal is showing, or if such has already been registered, will transfer the right of way as soon as the speed-timer allows.

### Two-Phase Controller—Means of Adjustment.

#### Timing Adjustments.

It will be appreciated that provision must be made for adjusting the various timing resistances. Ten-point rotary switches are provided and are so connected to fixed resistors that the following periods may be selected :

"A" road minimum green switch, 10 steps, 1, 2, 3, 4, 6, 8, 10, 12, 14, and 16 seconds.

"A" road maximum green switch, 10 steps, 5, 10, 15, 20, 25, 30, 35, 40, 45, and 50 seconds.

The "B" road switches are identical.

An "amber" switch is not normally provided, because in this country a 3-seconds' period has been standardised for the cautionary period. However, at some places abroad an adjustable amber is preferred, for which a further switch is fitted giving from 1 to 10 seconds in 1-second steps.

#### Accuracy of Timing.

In order to compensate for inaccuracies in individual resistances and condensers, each timing resistance train is separately fed through a trimming potentiometer. By this means the accuracy called for in British Standard No. 505 (the measured time to be within 7 per cent of the dial marking) is provided, with a wide margin to spare.

#### Facility Switch.

A facility switch is provided, and has three positions :

1. "Normal," giving vehicle-actuated operation.
2. "Fixed Time."
3. "Hand Control."

With the switch turned to the Fixed Time position, the detector connections are broken, and the *DE* relay permanently energised. The *RW* relay is also held continually operated, so that each road receives right-of-way in turn and retains it for the maximum period.

In the Hand Control position the switch similarly breaks the detector circuits, but *RW* is not allowed to become energised, and an external push-button is connected. By a single pressure of the button a change of right-of-way is initiated, the amber period being automatically terminated at the end of three seconds, and the green signal appearing in its new direction without further manipulation of the button. It is arranged that the button circuit remains broken for the appropriate minimum-green period following a change of right-of-way. This prevents the signals being switched too quickly by an operator in moments of excitement or forgetfulness.

#### Revert Switch.

As its name implies, this switch is provided to enable the right-of-way to be returned automatically to any selected phase. However, it becomes effective only in the event of there being no demands. (This is a feature which achieves fuller expression in multi-phase controllers.) The revert facility is especially useful for returning the right-of-way to arterial highways, and

for introducing artificial demands in the event of a detector being obstructed by road works, etc.

**Time Switches.**

Time switches are sometimes provided to switch the signals out at night, and an overriding switch is then added to enable the signals to be restored to immediate operation, without interfering with the setting of the time switch. It has now become the practice in this country for vehicle-actuated signals to remain in operation throughout the day and night.

**Multi-Phase Control.**

The elaboration of the circuits just described, to enable three or more roads, or road-groups, to be given right-of-way at distinct and separate times, is a matter of additional switching in the demand, and green extension circuits ; further lamp contactors and timing dials are also required. As may be supposed the complication is considerable. The same basis of operation is retained, and the three timing condensers *QNA*, *QNB*, and *QNC* carry out the timing of all periods with the help of relays *N* and *ST*.

## (2) THE ALL-RED FEATURE APPLIED TO THE NARROW BRIDGE.

The development which is now to be described is not new, having been introduced at several places in England before the late war, but its advantages from the point of view of traffic safety and the success of the methods employed to give effect to it have been amply demonstrated. The result has been that the vehicle-controlled all-red facility is being called for more and more.

Before the full significance of the vehicle-controlled type of " all-red " can be appreciated, it is necessary to know what is meant by an all-red period, and what it achieves.

The simple all-red period is a condition of fixed duration, wherein all signals display a single red indication. This involves that a change of right-of-way from one road to another instead of being accomplished in two steps : amber to both roads, and then green in the new direction, must be carried out in four, in the sequence : (1) amber to the road losing right-of-way ; (2) all signals red only ; (3) amber, with red, to the road about to receive right-of-way ; (4) green in the new direction. This sequence offers two main advantages at an ordinary crossing :

(*a*) Pedestrians are given rather more opportunity to cross (but unless the all-red period is made to last longer than required for traffic solely, full protection is not made available to the pedestrian).

(*b*) Right-hand turning traffic in either direction is given an opportunity to get away before more traffic is released into the crossing.

Judiciously used the all-red facility may actually increase the traffic capacity of a crossing, due to one or other of these advantages.

Generally the wider the crossing the greater is the need for an all-red period, and the longer it will be set to last. Also where there is a great deal of irregular turning traffic, or considerable gradients, or a large proportion of vehicles which because of their nature call for special treatment, the all-red interval is especially useful.

All-red periods of either fixed, or vehicle-controlled duration can be introduced into two-phase, or multi-phase, Autoflex controllers. In either case the basic principle is the same. It is therefore intended to describe the rather simpler two-phase case which will link very well with what has gone before. First, the method of securing the all-red period of the simple fixed duration type should be understood.

### CIRCUITS INVOLVED IN THE ALL-RED PERIOD.

Returning to diagram (*d*) of fig. 7 it will be remembered that the amber contactors for the *A* road and the *B* road were operated together ; in fact, were linked together at terminals *T*-*T*. For the simplest kind of signalling at an ordinary cross-roads this is just what is required, for the amber with red indication is given to one road at the same time that the amber is given to the other. To introduce an all-red stage it is necessary to withhold the right-of-way from the next road to receive it, until the road just losing it has been given first an amber, and then a red indication for a fixed—albeit adjustable—period. This mode of signal switching is easily secured in Autoflex equipment by breaking the link *T*-*T* just referred to, and arranging that the energisation of the two amber relays is carried out in three steps, each of which is timed by the " N " timer circuit in association with the amber timing resistance for the first and third steps, and with an " all-red " timing resistance in the second. The all-red condition may be arranged to occur in all changes or be restricted to selected changes. Thus in a three-phase system the feature could, for example, be brought in whenever the right-of-way changes from *A* to *B*, or *B* to *A*, but not in any change to or from *C*. Some 60 different combinations can be selected by interconnecting terminals with straps in the main relay set.

### VEHICLE-CONTROLLED ALL-RED.

It is frequently found that an all-red period which is indispensable during peak traffic hours becomes a time-waster under a limited number of traffic conditions occurring at other times. For example, there is no need for an all-red period at all, when the right-of-way is transferred from a road which has carried traffic, all of which has reached the far side of the crossing when the registered in the controller, and provided no vehicles had just traversed the detector *AD*, the signal *A* would turn to red, through the usual amber stage. If there had been traffic movement at the *A* end, the signal *A* would be held at green until such movements had ceased or until the *A* maximum period had expired, whichever was the sooner. The time which must elapse after the removal of green at *A*, to

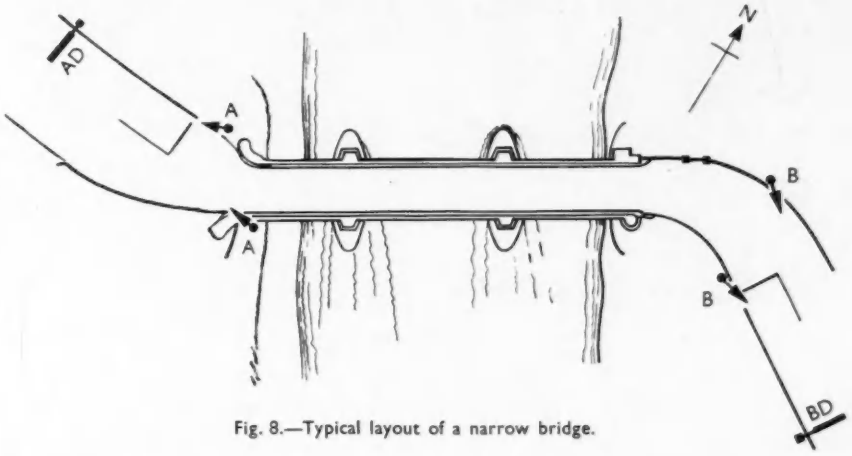



Fig. 8.—Typical layout of a narrow bridge.

change is initiated. There will be other occasions when the period could be shortened. In fact, to secure best efficiency under all densities and distributions of traffic, the traffic must control the all-red duration.

Extreme cases are to be met with in narrow bridges, tunnels, or approaches where there is room for traffic in one direction only at a time, and where an unrestricted view over, or through, the way is not possible.

### THE SIGNALLING OF A NARROW BRIDGE.

Fig. 8 is a plan of a typical narrow bridge, and it will be obvious that if the difficulties just mentioned apply here, then it will be of the greatest advantage to install signals at the approaches to the bridge, and to arrange that no vehicles are allowed on to the bridge while others are moving over it from the other side.

The operation of such a scheme can best be followed by watching the approach of an imaginary vehicle from the east.

It will be assumed that, when it arrives, the vehicle is faced with a red signal *B*, there having been no traffic in this same direction for some time, while there have been vehicles in the opposite direction. As our vehicle crossed the detector *BD*, a demand for right-of-way was the granting of right-of-way at *B* will depend upon the time which the last vehicle which passed *A* at green takes to arrive at the *B* end, and is obviously subject to wide variations. A single car may cover the distance in five seconds, a hay-cart (which is so frequently part of the same setting as the narrow bridge) may well take thirty or forty seconds. Also it must be remembered that the demand for right-of-way from detector *B* may not have arisen until a solitary vehicle from the west had got halfway over. At other times the demand may be registered at a moment when there has been no traffic which had not had time to clear the bridge in travelling from the west. In the latter circumstances the change of right-of-way should have begun immediately the demand was received, and have been completed without the inclusion of any all-red period.

Thus the all-red period must be capable of variation of from some fifty seconds down to nothing.

### THE ALL-RED SPEED-TIMER.

The fact that the speed of vehicles passing over the bridge is to have a direct bearing on the duration of the all-red period, at once suggests that a speed-timing circuit similar to fig. 5 could be employed. Such a timer is, in fact, used

additionally in the Autoflex variable all-red controller, a second *RW* relay being operated at the same time as that in the normal speed timer. The new relay is given the name *RWA* to distinguish it. It is arranged that the value of the timing resistances are such that when a vehicle

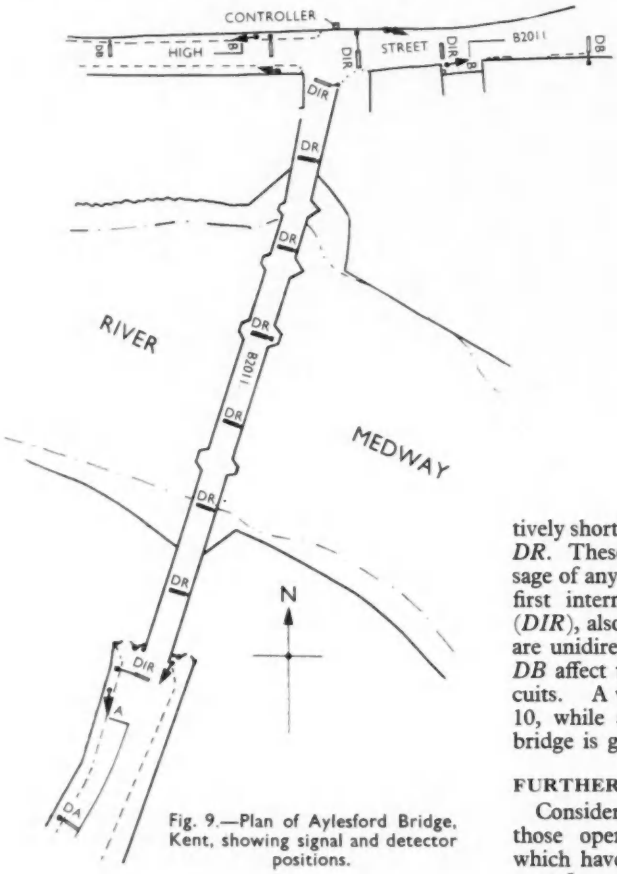



Fig. 9.—Plan of Aylesford Bridge, Kent, showing signal and detector positions.

passes over *AD*, the normal speed-timer measures a period which will keep signal *A* at green until the stop-line is passed, while the all-red timer measures a much longer period. Indeed, it might be supposed that it could measure the full period which the vehicle will occupy in crossing the bridge. However, the speed assessment at *A* is not likely to represent the speed of the vehicle throughout its journey over the whole distance, particularly if the bridge is of the hump-backed variety, and in practice several successive detectors are fixed in the narrow way. This enables the speed to be checked from point to point and a timing resistance to be used which will cover the vehicle from each detector to a point just beyond the next, and so on across the bridge.

Unless a signal change occurs during the period being measured by the all-red timer the latter will have no visible effect, but due to the demand indicated by our imaginary vehicle at *B*, and the turning to red of signal *A*, the all-red condition has been introduced and will persist until the expiration of the period which the all-red timer is marking off; whereupon signal *B* turns to amber with red, and then to green. Such is the general outline of the scheme, where demands are received at *B* while traffic is running (or has run) at *A*. If the same basis is applied in considering the conditions when it is from *A* that demands are received, and so on, a complete picture will be formed in the mind of the reader.

The plan of the old bridge at Aylesford in fig. 9 illustrates the way in which the narrow roadway is divided into comparatively short sections by the intermediate detectors *DR*. These are all capable of detecting the passage of any vehicle in either direction, whilst the first intermediate detectors in each direction (*DIR*), also the approach detectors *DA* and *DB*, are unidirectional. Only the detectors *DA* and *DB* affect the demand and green extension circuits. A view at the south end is shown in fig. 10, while a general impression of the type of bridge is given by fig. 11.

## FURTHER TIMING REQUIREMENTS.

Consideration has been confined so far to those operations of the all-red speed-timer, which have resulted from the passage of traffic over first and subsequent detectors. There are, however, certain conditions which require the actuation of the timer, or its equivalent, apart from direct detector actuation. They may be considered as follows:

(1) The granting of right-of-way to, say, *B* may take place as the result of a demand from one or more vehicles, after the system has been resting for some time with right-of-way to *A*, there having been no traffic in either direction. Alternatively, the change may take place after the normal speed-timer has completed its timing, but while vehicles from the west are still traversing the bridge. Or, again, it may occur as the

result of the maximum timer forcing the change, despite continued actuation of detector *AD*. In all these cases vehicles on the bridge had had an opportunity to notify their speed at the approach

Nor indeed, is there any knowledge of whether one, or many vehicles, had passed over *AD* and stopped at signal *A*. This absence of information following every minimum green period makes it

Fig. 10.—South end of Aylesford Bridge.

detectors—and therefore subsequently at each intermediate detector—thereby ensuring a sufficient all-red covering period for their full passage.

Yet a further condition characterises other changes, as in any change which follows immediately upon the expiration of a minimum green period. The fact that the change does occur at

necessary to introduce an artificial extension in the all-red timer, which will ensure that any vehicles that do start up when right-of-way is first given, and which are not followed by others operating *AD*, while *A* is green, will reach the first intermediate detector and so prevent the premature release of vehicles at *B*. The extension so introduced must be long enough to cover

Fig. 11.—Aylesford Bridge, Kent.

this moment, infers that vehicles on the bridge include those which had made the demand for the previous change to *A*. In regard to these, there is no knowledge of their speed (they had probably to slow down or wait at signal *A*) and the effect of their actuation of *AD* had been to operate the demand relay, not the speed-timer.

vehicles which are slow in starting, and in the Autoflex controller is adjustable. The period has come to be called by the rather odd name of " The Ghost Period ".

(2) In some circumstances the movement of traffic, or pedestrians, or even cattle about the bridge, has led to such prolongation of the all-red

Fig. 12.—(*a*) The Stonebow, Lincoln.

An equally historic background is found at the Stonebow in the City of Lincoln, fig. 12, where the vehicle-controlled all-red type of signal change is combined with a multi-phase signalling system. The all-red feature is chiefly concerned with getting the traffic through the old stone arch and across the mouths of busy roads which flank the wall on either side. The introduction of signals here has done away with the necessity for police control, which on certain days required the co-ordinated efforts of two traffic officers.

In fig. 13 there is an example of a narrow way which is not a bridge but a tunnel. It has been equipped with signals working on the principles set out for the bridge in fig. 8, and has proved its worth over a period of some

(*b*) Signalling system regulating multiple crossings at, and passage through, the Stonebow.

condition, that traffic movement is hindered. To prevent this a limit may be applied in the form of an all-red maximum. Admittedly, it may be argued that a period which has been proved necessary by the operation of the bridge detectors, should not be curtailed by the action of a blindly operating fixed period device. Suffice it to say that there are authorities who consider it desirable.

### TYPICAL EXAMPLES OF INSTALLATIONS OF THIS TYPE.

Reference has already been made to the old bridge at Aylesford, where in addition to the problem of protecting vehicles against collision on the bridge itself, the system is called upon to give protection at the High Street end where the only courses available to vehicles coming off the bridge involve the sharpest possible turns right, or left, into the narrow High Street. The traffic over the bridge varies from week-end coast-going traffic, to heavy industrial, agricultural and petroleum lorries during the week, with sufficient slow traffic of the hay-cart and milk-float variety to make the setting-up of the timing controls an interesting occupation.

ten years. The tunnel runs under the main railway lines at Ilford in Essex, and, before signalling, constituted a veritable death trap. In itself the tunnel is not very long, but the approaches to it are down-gradients, and completely blind. At times the noise of passing trains makes it impossible to hear the approach of vehicles from the other end. The route through the tunnel though not wide is important, as it serves as a convenient by-pass for main road traffic, which would otherwise be under the necessity of passing through the busy Ilford Broadway crossing.

Fig. 13.—Traffic tunnel, Mill Lane, Ilford.

### OTHER APPLICATIONS OF THE SAME FEATURE.

It has already been mentioned that the narrow-bridge type of layout illustrates an extreme form of vehicle-controlled all-red signalling. Between this application and the simplest, there lie an infinite number of possibilities. A very useful, and frequent, application with or without intermediate detectors has been made both here and overseas at the junctions where wide double carriageway roads are crossed by side roads.

It is perhaps significant that there is an increasing tendency for vehicle-controlled all-red changes to be called for by road authorities where in the past an all-red period of fixed duration would have been considered suitable, and, in conclusion, it should be said that, so far as is known, the vehicle-controlled feature is a British invention, and has certainly been brought to its present state of development by the close collaboration of British authorities—notably the Ministry of Transport, and the Police—with British manufacturers.

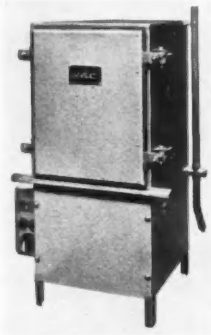
# NEW PRODUCTS

## 9 kW STEAMING OVEN

This new 9 kW steaming oven (HO 1147/8) has a capacity of 6 cu. ft. —the equivalent of 100 lbs. of potatoes, which it will steam in 40 to 50 minutes. A removable hanging rack and five wire baskets are provided.

The HO 1147 model is manually controlled by a 3-heat switch, while the HO 1148 has thermostatic control on 6 kW and manual control for the remaining 3 kW.

Each of the three sheathed wire immersion heaters is protected against burn-out due to water failure by its own cut-out (on A.C. only). The water feed from the ball valve tank to the heater well is specially



designed to overcome back conduction and circulation. The oven interior is made of heavy gauge tinned copper and operates at very little above atmospheric pressure due to the open steam vent provided in the bottom. The condensate runs to waste.

## MAGNETIC TAPE RECORDER

All the benefits of the magnetic tape recorder, whose many practical uses—beyond home entertainment—both public and private bodies will be quick to seize upon, are offered by this new model (BCS 3254). Recordings may be made from microphone, radio receiver or telephone line and then played back as often as desired, stored indefinitely or erased when no longer required.

The tape, which is made of plastic coated with iron oxide, will stand up to repeated recording and erasure without any loss of quality. Audio frequency response is flat within 4db between 40 and 8,000 c/s.

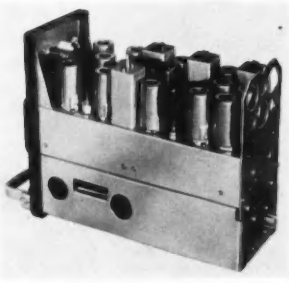
The instrument is simple to operate with push button controls for "Record/Play back," "Rewind," "Fast Forward Wind," and "Off." Recordings in the making may be

monitored continuously and marked with coloured paper tape; alternatively tinfoil tape may be used, in conjunction with the mechanism, to act as an automatic selector or stop.

The recorder is housed in a console walnut cabinet and works off a 200/250 volt 50 c/s supply. Power consumption is 200 VA.

## V.H.F. TRANSMITTER/RECEIVER FOR AIRCRAFT

The BRT 600 single-channel V.H.F. transmitter/receiver, designed for the small privately owned aircraft, provides two-way R/T contact with the ground and intercommunication between pilot and passenger, either of whom may operate the set. It weighs only 8·2 lbs. and its dimensions

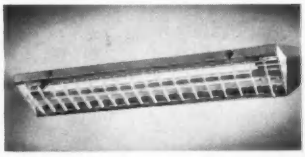


are: width, 3⅞ ins.; height, 7⅞ ins.; depth, 9½ ins. The complete assembly, consisting of transmitter/receiver and power supply units, fits into the standard S.B.A.C. racking system for civil aircraft.

The set is remotely operated from a simple control box in the cockpit. Only three controls are needed: on/off, volume and press-to-speak. There is no tuning control, but the set will operate on any required frequency (which must be preset) in the range 117·9 to 131·9 Mc/s. Power supply is taken from either a 12 or 24 volt battery via a rotary transformer.

## TWIN-LAMP FLUORESCENT SHOP WINDOW FITTINGS

A new range of twin-lamp fluorescent fittings for shop windows has recently been introduced, designed to provide a high concentration of light in windows of medium depth. The fittings are made for 2, 4 and 5 ft. lamps, and all are of identical cross section so that different sizes may be



butted together to give the required length of light source. They can be supplied with or without louvre frames, which are hinged to allow easy access to the lamps. Installation of the fittings is straightforward as they are complete with gear and internal connections.

The bodies and louvre frames are of rust-proofed sheet steel finished in white stove enamel, and the reflectors are of aluminium, electro-brightened and anodised.

## GECOPHONE JUNIOR

The Gecophone Junior is a versatile instrument designed for small private telephone systems. In order to satisfy widely varying requirements as economically as possible, five models, similar in design and construction, have been produced: Direct Working (between two), Battery Call (between three or more

n conjunction with battery call witchboard), Apartment Flat (in onjunction with Reply Panel), Reply nd Call (for use with loudspeaking intercommunication system), 5-line push button intercommunication (providing full direct intercommunication between up to six stations).

Each model is available in black or ivory plastic case and standard or tropical finish. The same instrument may be mounted on table or wall, since the streamlined cradle will hold the handset in either position.

The Gecophone Junior is marketed in the U.K. by The Reliance Telephone Co. Ltd. (a subsidiary of the G.E.C.).

## INDUSTRIAL BROADCAST UNIT

This instrument (BCS 2352) is, in effect, the nucleus of a small radio relay system with additional facilities for gramophone and microphone input. With an undistorted output of 18 watts it will operate up to 40 extension loudspeakers of a size suitable for hotel bedrooms, hospital wards, offices, etc., or alternatively up to 12 larger loudspeakers each capable of serving a room of 5,000 cubic feet capacity.

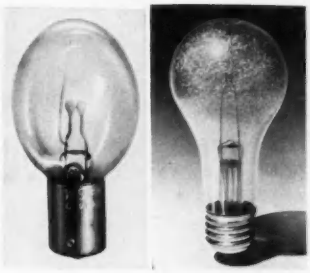
The required input is selected by means of five push-buttons for gramophone, microphone and the three

wavebands (one medium and two short in the overseas and long, medium and short in the home model). Five further push buttons control output switching, i.e. off ; external speakers on with internal speaker off, low or high ; and external speakers off with internal speaker high.

The cabinet is of polished walnut and the whole is built to tropical specifications. Power supply is 200-250 volts A.C., 50-100 c/s.

## TWO NEW PHOTOFLASH BULBS

The **Speed Midget** (below, left) is one of a new range of photoflash bulbs being developed by the G.E.C. to meet the needs of present-day photography. The flash is produced by the combustion of primer paste



(zirconium with a suitable oxidising agent) and not, as in previous types, of aluminium foil ; as a result the delay between the application of volts and the start of the flash is reduced from 15 to 5 milliseconds. Since 5 milliseconds is the average time taken for a " between-the-lens " shutter to open fully, no synchroniser is needed with the Speed Midget, and a pair of contacts on the shutter mechanism may be used instead. The flash lasts about 10 milliseconds and can thus be easily synchronised with an exposure of 1/100th second. Total light output is approximately 3,500 lumen/seconds.

The **No. 22** (above, right), the second photoflash bulb in the new range, is the first shredded foil bulb to be produced by the G.E.C., and its function will be to replace the now obsolescent leaf foil " Sashalite ". By using shredded foil it is possible to limit the variation in performance from one bulb to the next to a degree quite unattainable with leaf foil, and thus the No. 22 goes a long way towards meeting the demands of modern synchronised flash photography.

Time to peak of flash is the standard 20 milliseconds and total light output is 60,000/65,000 lumen/seconds.

## 12 INCH MARINE FAN

The V150 is a 12 inch marine fan designed for either bulkhead or deckhead mounting. It is fixed in position by means of a horseshoe backplate, to which it is clamped by a hand screw ; and by siting further backplates in suitable alternative positions the fan may be moved readily from one to the other as desired.

The fan is driven by an enclosed ventilated D.C. motor, 110 or 220 volts, with split windings, so that two speeds are obtainable without a separate regulator. It is controlled by a three-position tumbler switch (two speeds and " off ").

Another version (V 152) is also available ; this incorporates oscillating gear enclosed in the motor housing, but is suitable for bulkhead mounting only.

Both fans have white enamelled brackets and bodies and chromium plated blades and guards, and both are fitted with radio interference suppressors.

# TECHNICAL LITERATURE

A DIGEST OF RECENT BOOKS, ARTICLES AND PAPERS, BY MEMBERS OF THE G.E.C. AND ITS ASSOCIATED COMPANIES.

## FLAMEPROOF SWITCHGEAR.

**By C. J. O. Garrard (Switchgear Dept., Witton Engineering Works).**
*British Engineering, April, 1949.*

A general survey of the principles of construction of apparatus for use in coal mines and other situations where inflammable atmospheres may exist, with descriptions of typical apparatus.

## ELECTRONICS IN HEAVY ENGINEERING.

**By W. Wilson (Development Laboratory, Witton).**
*British Institution of Radio Engineers. August, 1949.*

A general survey of the part that electronics has already played in industry and a prognosis of its future applications.

## TELEPHONE RELAYS AND THEIR USES IN ELECTRONIC CIRCUITS.

**By A. A. Chubb (G.E.C. Telephone Works, Coventry).**
*Electronic Engineering. June, July, 1947.*

The article describes the more common forms of telephone-type relay available and gives their electrical and mechanical characteristics. Special problems arising in connection with their use in valve circuits are listed, and the determination of their operation under various conditions is explained. A number of circuit elements are described, showing how relays may perform various functions.

## PLANAR ELECTRODE VALVES FOR V.H.F.

**By the Research Staff of the M.O. Valve Co., Ltd.**
*Wireless World. May, 1949.*

Describes progress made in improving the high frequency performance of triodes and pentodes and the general design features of parallel electrode valves (planar electrodes) for operation at frequencies up to about 4,000 Mc/s. Operating data are given for the triode E1714, with diagrams of electrode structure.

## POWER DIODES.

**By E. G. Rowe, R. E. B. Wyke and W. MacRae—Research Staff of M.O. Valve Co., Ltd.**
*Electronic Engineering. July, August, September, 1948.*

A series of articles describing the design, features, and operating characteristics of vacuum and gas-filled rectifier valves. Diagrams and curves showing the effect of design on operating ratings and characteristics of typical rectifiers are given.

## ECONOMICAL 50 WATT AMPLIFIER.

**By G. R. Woodville (Research Staff of the M.O. Valve Co., Ltd.).**
*Wireless World. December, 1948.*

Describes improvements to audio frequency power amplifiers by the introduction of a new rating of the KT66 for 50 watt output per pair in push-pull, with fixed bias. Performance curves of a typical amplifier and circuit are given.

## STRESSES IN TWO-WIRE GLASS-TO-METAL SEALS (396).*

**By O. Adams (Research Laboratories).**
*Trans. Soc. Glass Techn., Vol. 32, pp. 99-112, 1948.*

A brief discussion of the behaviour of glass in plane stress when examined in plane polarised light is followed by a description of the estimation, by Filon's graphical integration method, of the principal stresses in flat two-wire glass-to-metal seals.

## RESISTIVE FILMS IN VALVES —EFFECT ON INTERELECTRODE CAPACITANCE (397).*

**By E. G. James and B. L. Humphreys. (Research Staff of the M.O. Valve Co., Ltd., at the G.E.C. Research Laboratories).**
*Wireless Engineer, Vol. 26, March, 1949.*

This paper applies Professor Howe's analysis of the behaviour of resistances at high frequencies, to the behaviour of interelectrode capacitances in the presence of resistive films between the electrodes. It is shown that the capacitance of such films varies inversely as the square root of the frequency at high frequencies and tends to a limit at low frequencies. The importance of the frequency in the measurement of interelectrode capacitances is demonstrated experimentally.

## NEW LAMP DEVELOPMENTS (401).*

**By N. L. Harris (Research Laboratories).**
*Trans. I.E.S., Vol. 13, No. 8, 1948.*

The history of electric lamp development has been one of steady improvement in the efficiency of production of light. The lamps used to-day for general lighting have 15 to 20 times the efficiency of those first developed some 70 years ago. This paper surveys recent achievements and indicates the probable lines of future developments.

## AN ELECTRICAL METHOD OF MEASURING WATER VAPOUR PRESSURE IN A SEALED-OFF DISCHARGE TUBE (404).*

**By B. N. Clack (Research Laboratories).**
*Jour. Sci. Insts. Vol. 26, No. 2, February, 1949.*

An electrical method of measuring water vapour pressure in small sealed-off valves is described in which the change in voltage drop across a glow discharge in the vapour is studied as the envelope is cooled. The method was developed primarily for measuring the partial pressure of water vapour in argon-water vapour in Radar TR switches, but the application to other cases is discussed. Results are repeatable and are rapidly obtained. Vapour pressures of water as low as 0·5 mm. and quantities as small as 0·1 $\mu$g. can be estimated.

## DIRECT READING FREQUENCY MEASURING SET.

**By F. C. F. Phillips (G.E.C. Telephone Works, Coventry).**
*Journal of the British Institution of Radio Engineers—Vol. 8 pp. 4-15, January and February, 1948.*

The principle involved in the equipment is the successive heterodyning of the signal to be measured by decade stages obtained from a source of standard frequency. The initial digit of each decade group is shown on an illuminated dial and the final value (below 1,000 c/s is read from a deflection-type frequency meter.

The paper describes the problems involved in devising such a system, and their solutions to enable unambiguous readings to be obtained by a relatively unskilled operator.

This paper has been awarded the Institution's Marconi Premium for the most outstanding engineering paper published in the Journal of the Institution during 1948.

***A limited number of reprints is available of those papers marked with an asterisk. Copies may be obtained on application to the Editor, G.E.C. Journal, Magnet House, Kingsway, W.C.2.**